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This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

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INVENTOR(S)		
Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
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Additional inventors are being named on the 1 separately numbered sheets attached hereto

TITLE OF THE INVENTION (500 characters max)

HYPERSPECTRAL IMAGING METHODS AND DEVICES

Direct all correspondence to: CORRESPONDENCE ADDRESS

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ENCLOSED APPLICATION PARTS *(check all that apply)*

☒ Specification *Number of Pages* 13
☒ Drawing(s) *Number of Sheets* 49
☐ Application Data Sheet. See 37 CFR 1.76
☐ CD(s), Number
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Respectfully submitted,
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[Page 2 of 2]

Number 1 of 1

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Hyperspectral Imaging Methods And Devices

Provisional Patent application

Inventors: Andreas C. Coppi, Groton, CT; Richard A. DeVerse, Kailua Kona, HI; William G. Fateley, Manhattan, KS; Frank B. Geshwind, Madison, CT.

The present invention relates to methods and devices for hyperspectral imaging. One embodiment, called "NSTIS", for Near-infrared Spectral Target Identification System, is a DMD-modulated-aperture imaging spectrograph system, operable in the near-infrared. It includes fore optics for imaging a scene of interest, a micro-mirror array spatial light modulator (SLM or DMD), a diffraction grating and an infrared camera, together with the necessary optics to transfer the image between these components, and electronics to drive the SLM.

The present invention related to further embodiments, details and improvements on such a system that has been described in US. Patent Application Serial No. 09/798,860, filed March 1, 2001, titled "System and Method for Encoded Spatio-Spectral Information Processing,", U.S. Patent No. 6,392,748, US Patent No. 6,046,808 and US Patent No. 6,128,078. These patents and application are herby incorporated by reference.

One Possible General layout is illustrated in figure 1

For further illustration, figures 6 and 7 show photographs of a Plain Sight Systems DMD modulated aperture imaging spectrograph system built to operate in the visible wavelength range.

In a preferred embodiment, a scene or object of interest is imaged onto a spatial light modulator. The spatial light modulator is used to pass or reject the spatial resolution elements of the image. Spatial resolution elements that are so

selected propagate through an imaging spectrograph system and are spectrally imaged onto a focal plane array sensor.

The digital micromirror device (DMD) spatial light modulator (SLM) presents a challenge in that typical imaging optics have image planes that are perpendicular to the optical propagation axis Z. When the object is imaged by these conventional optical imaging systems onto the DMD then the image now becomes an object for the imaging spectrograph and the DMD can selectively relay spatial resolution elements of this object-image onto the imaging spectrograph portion of the system. This however requires that special optical systems capable of handling this condition of the tilted object. Furthermore the resultant image is tilted. Generally speaking, this results in poor optical performance for imaging systems and typical imaging systems cannot cope with this condition at low F numbers of operation. Figure 2 shows an example of the tilted object plane imaged onto a resultant tilted image plane using a simple image relay lens system.

Figure 4 shows a model of a lens imaging a source onto the DMD SLM through a Near Infrared optimized total internal reflection (TIR) prism assembly that functions to reduce effective F# of operation by creating a greater path divergence of the incoming and outgoing beam of light. This prism assembly can be so constructed that it functions to separate both the “on” deflected light (+10 degree mirror position) and the “off” light (-10 degree mirror positions). Figure 3 only shows the “on” or (+10) degree position of the mirrors so as to direct the light to the subsequent optical system such as the imaging spectrograph.

One embodiment of a DMD enabled staring spectral imaging system is shown in Figure 5. This configuration uses a typical imaging lens to present an image of the object under observation to the DMD SLM through a near-infrared (NIR) TIR

prism assembly. The spatial resolution elements that are selected to pass onto the relay lens system and transmission diffraction grating and are presented to the camera 2D sensor array or focal plane array(FPA)

One can also employ a system where two lens sets are used in conjugate positions such that the first lens set collimates the light from the DMD SLM to the diffraction optical element and the second lens focuses the dispersed light onto the FPA.
Note that the lenses are either refractive elements or reflective optical systems.

A preferred embodiment uses all reflective optical components so that the system is not limited by the spectral range of transmission of the refractive elements used in the system. All reflective optical elements also permit chromatic error free operation. An improved embodiment of the staring hyperspectral imaging system uses a special optical relay system developed by plain sight systems to place the image onto the DMD in the preferred manner where the image plane that is perpendicular to the optical propagation axis Z is made tilted for presentation to the DMD without a TIR prism assembly. Figure 8 below shows an optimized all reflective model of an optical systems that takes an object plane and presents a tilted image at precisely the correct angle to the DMD so as to allow the use of typical optical sub-systems to receive the spatial resolution elements that are selected to propagate through the system in a conventional manner. This is important because most spectral imaging systems are very sensitive to the degree of collimation for resolution elements impinging upon a diffraction element. If the DMD object that is a result of the primary object image is tilted the spectral imaging system has difficulty if spectrally re-imaging the primary object at the FPA.

In another embodiment, the reflective optics described are used with a TIR prism. Figure 9 shows an extension of the system shown in Figure 8 for use with a TIR prism assembly.

Figure 10 shows one preferred embodiment of the staring hyperspectral imaging system as designed in one PSS prototype application. A refractive camera lens receives the light from the source object and images it onto the object plane of the all reflective transfer optical system that takes this conventional perpendicularly presented image with respect to the optical axis from the conventional camera lens system and presents it through the TIR prism to the DMD micro-mirror plane in a tilted fashion with respect to the optical axis such that the selected spatial resolution elements can propagate to the imaging spectrograph portion of the system. This condition allows more typical imaging optical systems to be used and improves the collimation of all of the desired spatial resolution elements used in the DMD SLM. Improving the collimation improves the effectiveness of the diffractive element and improves the subsequent image quality as it is focused by the focusing optical elements in the spectrograph portion of the system.

Figure 11 shows a solid model of the system shown in Figure 10

Figure 12 shows the imaging spectrograph portion of the PSS prototype hyperspectral imaging system using conventional refractive optical elements as made possible by the PSS proprietary tilted optical relay design to the DMD SLM.

Figure 13 shows a map of DMD SLM micromirrors to the FPA. The DMD micro-mirror representation is shown on the left of the figure 13 in black. The corresponding spectrally dispersed images of the of the micro-mirror column are shown in black at the representative FPA on the immediate right. As the column of micro-mirrors that are selected to be in the "on" condition move from left to right so to does the spectrally dispersed images of the column move from left to right on the FPA for a given spectral range of operation. One can also select a multi-tude of columns simultaneously that have the effect of presenting a mulit-

tude of overlapping spectral images onto the FPA. This method is called multiplexing and is described elsewhere.

Optics for Hadamard Encoded Apertures

Hadamard optical systems utilize spatially encoded apertures that can be employed either at the entrance aperture of optical system, the exit aperture or both. They have the common attribute that they encode the available aperture spatially where the spatial resolution elements that make up the encodement dictate the spectral, spatio-spectral or spatial resolution elements that propagate through the optical system including diffractive optical elements and on to the sensor or exit aperture. These masks have some spatial extent that places special requirements on the optics of the system. As the encodement mask grows either by longer length encodements with fixed sub-apertures or as the sub-aperture dimension grows for a fixed encodement length, the spatial resolution elements making up the sub-apertures in the encodement mask depart from the optical axis. When the resolution elements depart from the optical axis or paraxial condition it becomes important to employ optics that can image the off axis resolution elements without inducing excessive aberrations that degrade the performance or cripple the advantages gained by HT multiplexing.

Typically the optical path for conventional monochromators begins with a source that is focused onto an aperture plane that has a large aspect ratio aperture know as a slit. This slit is often very small in extent in the dispersion plane compared to the other extent in the spatial plane. However, it is not required that this aspect ratio is large. If the aspect ratio is close to 1 then simple spherical optics can be employed that perform well as long as the departure from the optical axis is kept to a minimum. However, most monochromators have a large aspect ratio in order to increase the opportunity to maximize throughput, and detectors must be able to "see" the large extent of the slit aperture. The light entering the slit aperture is then dispersed and focused onto an exit slit aperture. Monochromators are only required to perform well on the optical axis and do not typically employ optics that can manage rays that depart from the optical axis in

the plane of dispersion as required by HT multiplexing instruments. To employ encoding techniques the optical system is required to utilize optical performance attributes normally found only in imaging and spectral imaging systems. This requirement is driven by the extent of the encoding mask. The extent of the encoding mask is governed by the diffraction limit of the wavelengths within the bandpass, the encodement length N and the attributes of the optical system.

In a conventional dispersive spectrometer the radiation from a source is collected and separated into it's individual spectral resolution elements by a spectral separator such as a diffraction grating or prism and then is collected and focused for spatial presentation on a focal plane. The dispersive spectrometer uses a single exit slit to select one spectral resolution element of N spectral resolution elements for measurement by the detector. The Hadamard transform spectrometer (HTS) uses an array of slits (i.e. a mask) at the focal plane to select one more than half, (N+1)/2, of the spectral resolution elements at the focal plane for measurement by the detection system. The optical challenge to effect an HT multiplexing spectrometer is to collect all of the spatially distributed individual band pass images of the entrance slit and transfer them to as small detector as possible. One desires to keep the area of the detector at a minimum as the noise of many detectors increases with the square of the area. If the optics are able to illuminate a single detector element with all of the available light impinging upon the focal plane containing the spatially distributed images of the slit for each of the N band pass resolution elements, a multitude of spectral resolution elements can be measured simultaneously using a single detector element. This arrangement results in a multiplexing spectrometer. The recovery of N spectral resolution elements requires measuring the detector response for N different encodements of (N+1)/2 open mask elements. The raw data is recorded as the detector response versus encodement number and is called an encodegram. Hadamard transformation of the encodegram yields the spectrum.

The History of Applied Hadamard Multiplexing

The Hadamard transform instruments developed in the 1960s and 1970s employed moving masks. Significant problems such as misalignment and jamming associated with a moving mask led to a reputation of poor reliability and contributed to a dormant period in the development of HTS and HTI. Interest was rekindled in the 1980s using stationary Hadamard encoding mask based on liquid crystal (LC) technology. The first generation 1D stationary Hadamard encoding mask was a cholesteric LC with N = 127 mask elements and used polarization as its operating phenomenon. Two parallel polarizers and rotation or lack of rotation of the polarized radiation generated the opaque and transparent states, respectively. The second generation 1D stationary Hadamard encoding mask was fabricated using a polymer dispersed liquid crystal (PDLC) material with N = 255 mask elements and used light scattering as its operating phenomenon. The PDLC contained LC droplets dispersed in a polymer matrix whose index of refraction matched the index of refraction in one direction in the birefringent LC droplet. Alignment of the LC droplets optical axis under an applied voltage removed discontinuities in index of refraction at the polymer matrix/LC interface to generate a good transparent state while random orientation of LC droplets in the polymer matrix generated the opaque state from light scattering by the discontinuities in index of refraction at the polymer matrix/LC droplet interface. A 2D stationary Hadamard encoding mask was also based on LC technology. A fero-electric liquid crystal (FLC) positioned between a pair of polarizers with perpendicular orientation operated as an electro-optic half-wave plate when a + value of applied voltage rotated the plane of polarization by 90 degrees to produce the transparent state and a - value of applied voltage left the plane of polarization unaltered to produce the opaque state.

Development based on stationary Hadamard encoding masks continued in the 1990s and a 2D moving Hadamard encoding mask was also fabricated and used to perform imaging in the near-infrared and mid-infrared spectral regions. Note that the mid-infrared spectral region is not generally accessible via Hadamard encoding masks based on LC technology since any LC material is

expected to have strong absorption bands in the mid-infrared spectral region. From the mid 1990s to the present the stationary Hadamard encoding mask of choice for the visible and near-infrared spectral regions has been the digital micro-mirror device (DMD), a device based on micro-optoelectromechanical systems (MOEMS) technology and developed by Texas Instruments for projector display applications. One DMD format incorporates 508,800 micro-mirrors in a 848 column by 600 row array that is 14.4mm wide by 10.2mm high. Each individual micro-mirror is 16microns square and adjacent micro-mirrors are separated by a 1micron gap.(need Greekl lc letter mu followed by m here) The micro-mirrors are individually addressable and rotate by +10 or -10 degrees about the diagonal axis to produce binary "on" and "off" states. The on state has T_t determined by the mirror reflectivity and approaches 1 while the off state approaches $T_0 = 0$. The ideal condition of on and off is not realized due to diffraction of the light off of the small and periodic features of the micro-mirror device. The DMD is an array of spatial resolution elements that may be selected as groups of super-resolution elements or as individual resolution elements consisting of a single micro-mirror. The DMD resolution elements are realized as spectral resolution elements in the spectrometer with the columns attributed to the frequency or wavelength dimension and the rows attributed to the slit height dimension. The DMD resolution elements are utilized as spatio-spectral resolution elements in the imaging spectrograph with the columns as the frequency or wavelength dimension and the rows as a vertical spatial dimension with the horizontal spatial dimension being accessed, if desired, by translating the sample relative to the imaging spectrograph. The DMD resolution elements are spatial resolution elements in the imager with the columns for the horizontal dimension and the rows for the vertical dimension and the frequency or wavelength dimension provided by other instrumentation. If a photo-acoustic detection system is present then the depth dimension of the sample may also be accessed by changing the modulation frequency used in the photo-acoustic detection system.

Some important features of HTS to keep in mind are:

(1) It is a dispersive technique using a spectral separator

(2) It is a multiplexing technique using a single-element detector

(3) It uses a Hadamard encoding mask (multi-slit array) in the focal plane

(4) It sends one more than half the resolution elements to the single-element detector in an encodement

(5) It uses a number of encodements equal to the number of resolution elements desired and the number of mask elements (pixels) in the stationary Hadamard encoding mask (a moving Hadamard encoding mask has 2N – 1 mask elements)

(6) It has each encodement contain a different combination of one more than half the resolution elements.

(7) It has as its primary data the encodegram, a record of detector response versus encodement number.

(8) It uses a FHT of the encodegram to decode the encodegram and generate the spectrum or image.

Note that all of these except for item (1) also apply to HTSI and HTI. The DMD promises to be the best Hadamard encoding mask yet developed for the visible and near-infrared spectral regions. However, its potential applications in spectrometry and imaging are by no means limited to HT techniques since the information corresponding to any micro-mirror in the DMD may be included in or excluded from any measurement as desired by the investigator . An instrument with no moving parts other than the micro-mirrors in the DMD promises to provide a compact and robust instrument for operation in potentially hostile environments ranging from process control to outer space. It is our belief that the combination of a DMD with a single-element detector may provide an important advance in spectroscopic instrumentation and that instrumentation based on the

DMD may lead to a host of environmental, industrial, medical, and military applications.

Plain Sight Systems Technology Overview

- **Multiplexed Spectral and Hyperspectral data and imagery**
- **PSS's MEMS-based multiplexing**
- **NstisApp software for interfacing to NSTIS**
- **Optical-digital domain Endmember processing**
- **Advanced ATR and Feature extraction algorithms**

Plain Sight Systems Technology, Some Advantages

- **Extended of hours of operability**
- **Operability where conventional single slit spectral imaging systems fail**
- **Improved signal to noise ratios**
- **Increased sensitivity for chemistry and features of interest in hyperspectral imagery and spectral data**
- **Better Pd/Pe ratios**
- **Faster information delivery**
- **Smaller bandwidth for telemetry of data**
- **Reduction in post processing of data**

Spec	**Performance**
• **Sampling spectral**	**1.5625nm**
• **Spectral resolution**	**< 10nm**
• **Working F#**	**< 5.6**
• **Data collection time**	**10 sec / datacube (typical. Depends on light levels)**
• **Datacube**	**up to 512x512x532 (256x256x266 also)**

Vis-NIR: What it Does

Silicon spectral range 400nm-1100nm

Cube: 400X600spatial X 255 spectral

- **Staring Hyperspectral imaging system**
- **Programmable information collection**
- **Improves SNR**
- **Faster image cube acquisition**
- **Night vision capable**
- **Variable resolution**
- **Adaptive Chemometrics in the optical domain**

Vis-NIR: Applications

- **Spectral imagery**
- **Dermatology**
- **Pathology**
- **Chemical detection in scenes**
- **Target recognition and identification**
- **Process control – Agriculture/Industry**

NSTIS: What it Does

Spectral range InGaAs: 900nm-1700nm

Hyperspectral cube as large as: 512X512spatial X 266 spectral

- Staring Hyperspectral imaging system
- Programmable information collection
- Improved SNR over raster scanning methods
- Faster image cube acquisition
- Night vision capable
- Variable resolution
- Adaptive Chemometrics in the optical domain

NSTIS: Applications

- NIR Spectral Imagery
- Pharmaceutical Classification
- Process control Agriculture/Industry
- Plastics sorting
- Target identification and classification
- Adaptive chemometry in images
- Night-time spectral imagery
- Taking funny pictures of your friends
- Development of chemometric methods

HSE: What it Does

- Allows the user to quickly view and manipulate hyperspectral data cubes in a flexible interface.
- Develop chemometry and applied methodology for complex sample matrices and environments
- Application of LDB analysis

HSE: Uses

- Principal Component Identification
- LDB
- Hierarchical Clustering
- Normalization
- Intuitive Training Set Interface

NSTIS App Software

- For use with NSTIS to perform on the fly scene selection and averaging
- Allows easy access to a hyperspectral datacube
- Windows based GUI application for hyperspectral image acquisition.
- Optimized hyperspectral data acquisition
- Preview of spectra from image regions, including single beams, ratios, dark noisecorrections and 100% line images.
- fast local-orthogonal component analysis algorithm for quick data exploration.

In a preferred embodiment the system includes software for acquisition of hyperspectral data, and a user interface for interactively selecting regions from a 2D projection of the 3D hyperspectral datacube. Such an embodiment can also include software for computing features of the selected regions, and display of the 3D datacube, project into 2D via the selected features. One example of a way to do this would be to compute the mean spectral vector in each region, and then compute a Gram Schmidt orthogonalization of the selected vectors. When there are 3 selected vectors, the output of the Gram Schmidt algorithm can be sued to compute 3 spectral inner products over the datacube, and the results used to render an RGB image of the datacube. The process can then be iterated, providing the user the ability to select regions in the original and the processed 2D projections.

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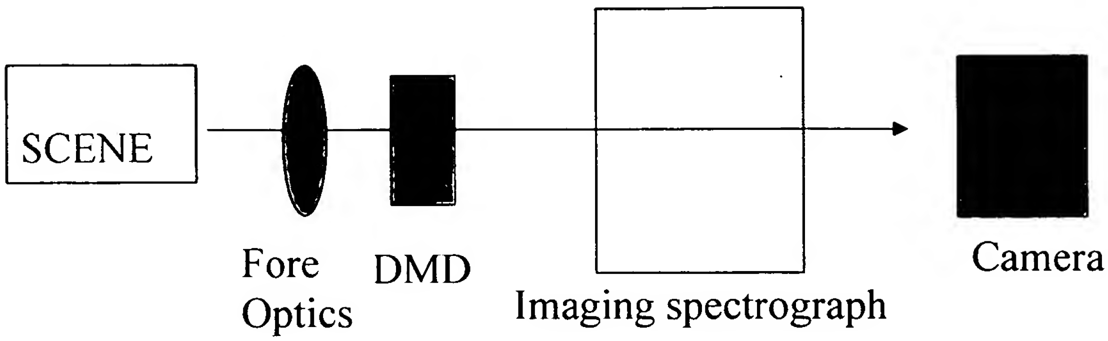


Figure 1: A general layout for NSTIS

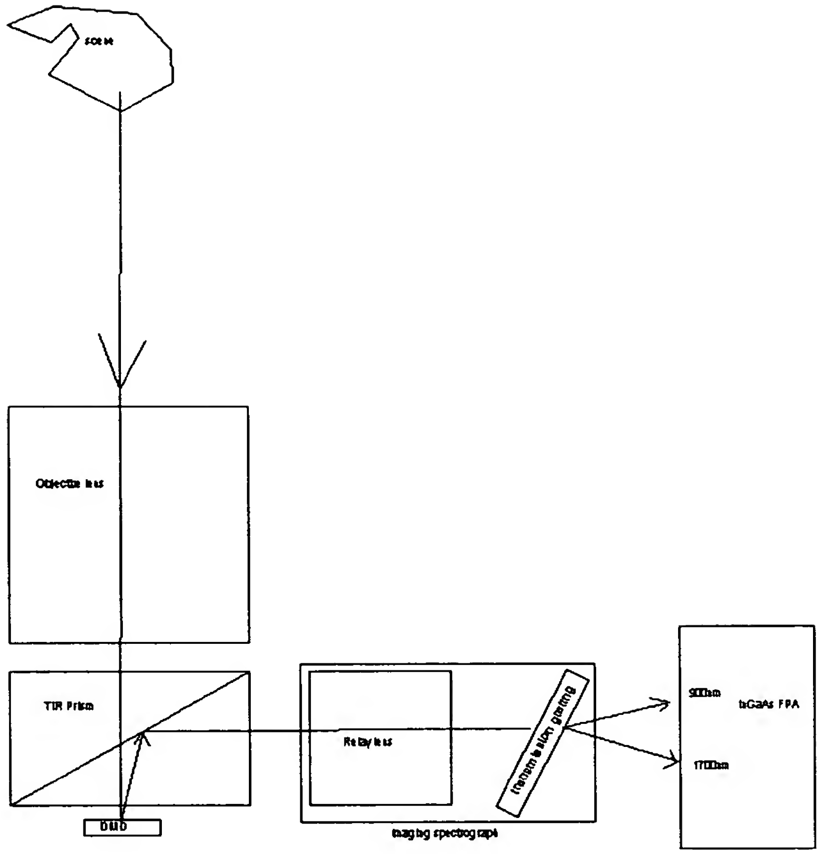


Figure 2. One embodiment of a basic system layout.

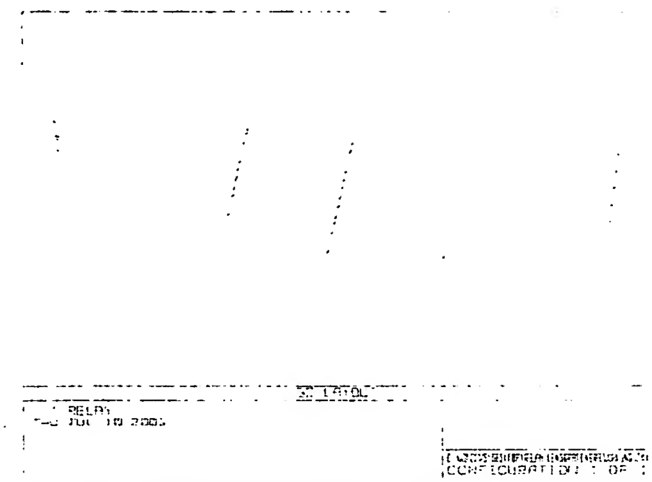


Figure 3. Example of asymmetric imaging relay spectrograph using simulated DMD tilted object, two paraxial lenses, a grating and a tilted FPA at the image plane.

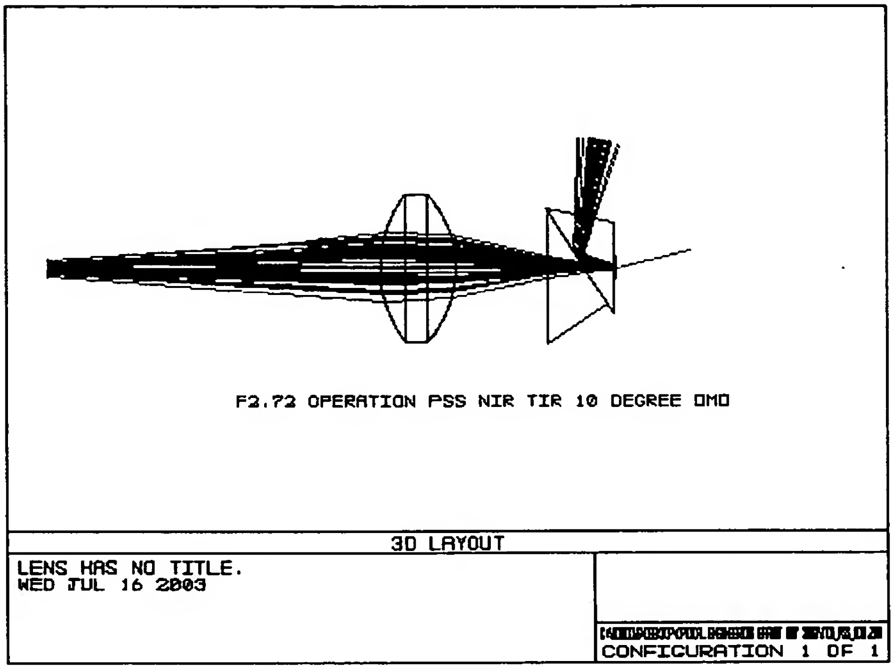


Figure 4. Imaging lens and TIR prism example for improving F# of operation using the DMD as an SLM to select spatial resolution elements of an image to pass to subsequent optical elements of the imaging or spectral imaging system.

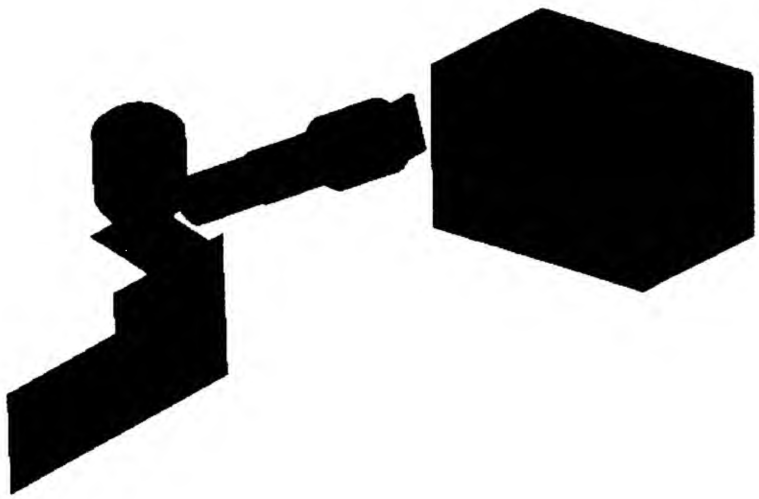


Figure 5. A typical camera lens (near the upper left of the drawing, shown in green in color renderings) receives light from the source object and re-images the object onto the DMD where the plane of micro-mirrors are surface normal to the optical propagation axis Z. The DMD can then be used to select which spatial resolution elements of the image will propagate through the TIR prism and into the relay lens, through the transmission grating and spectrally imaged onto the camera sensor or focal plane array (FPA), shown on the right of the drawing).

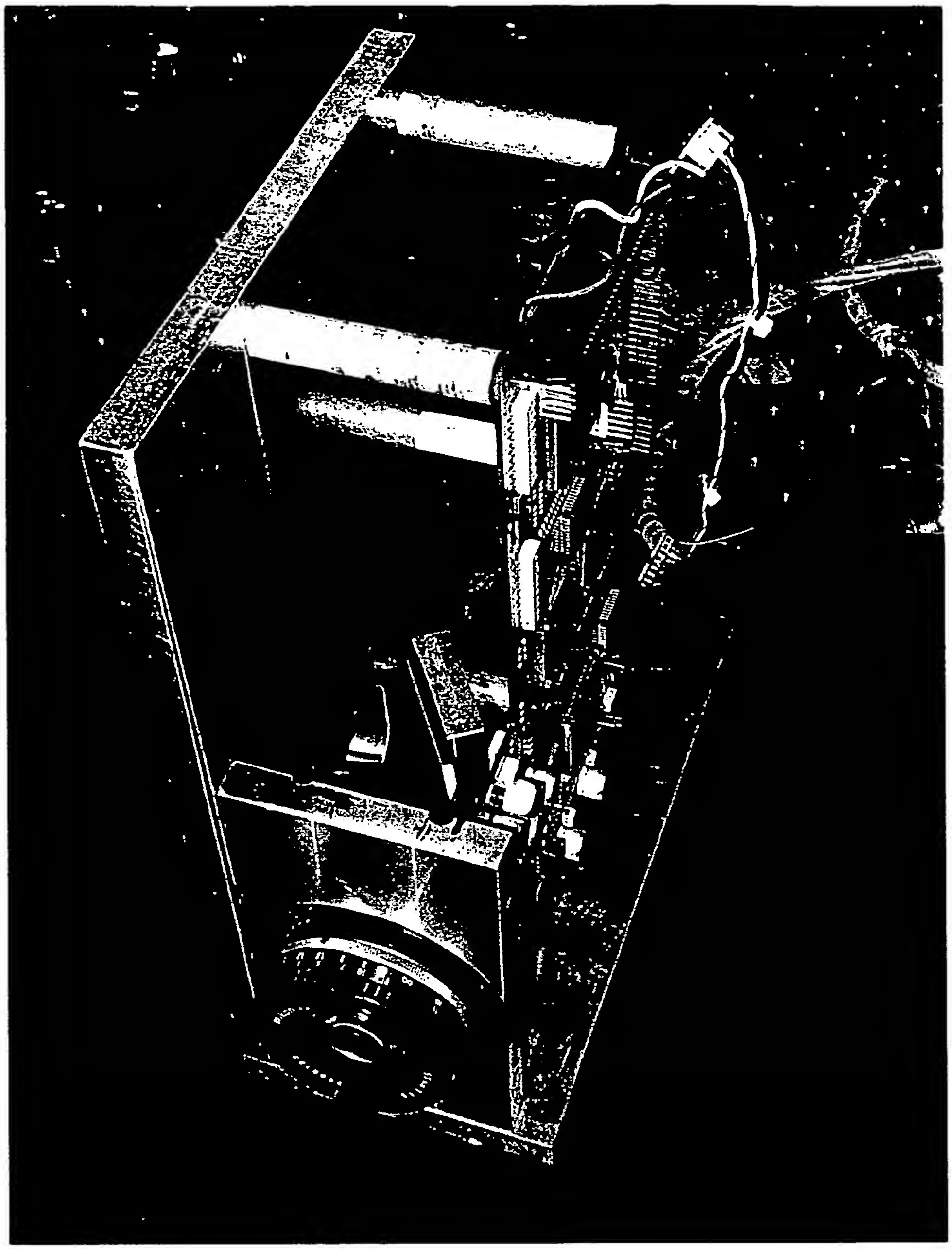


Figure 6: Visible System DMD module and imaging objective

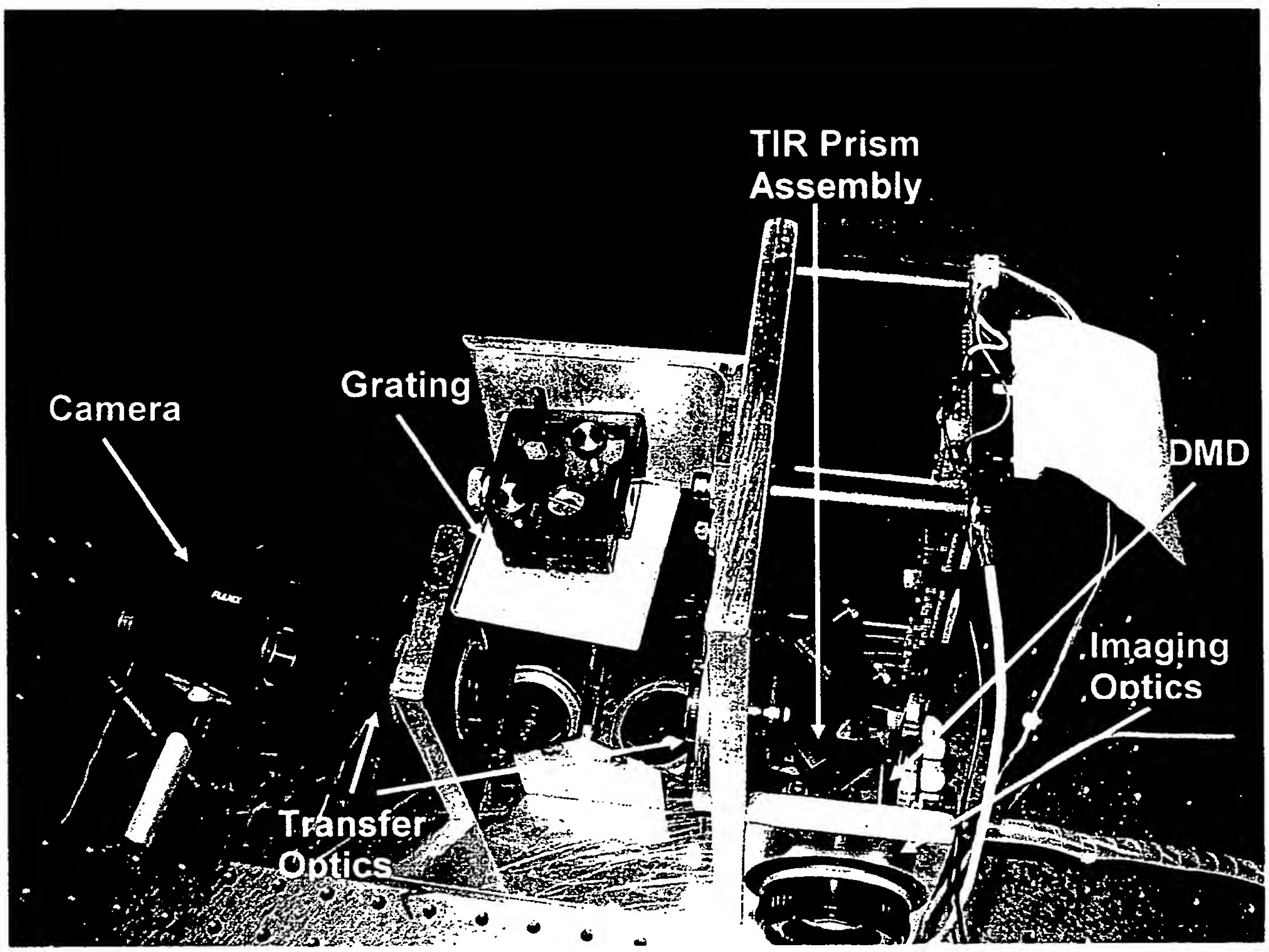


Figure 7: Visible System complete prototype

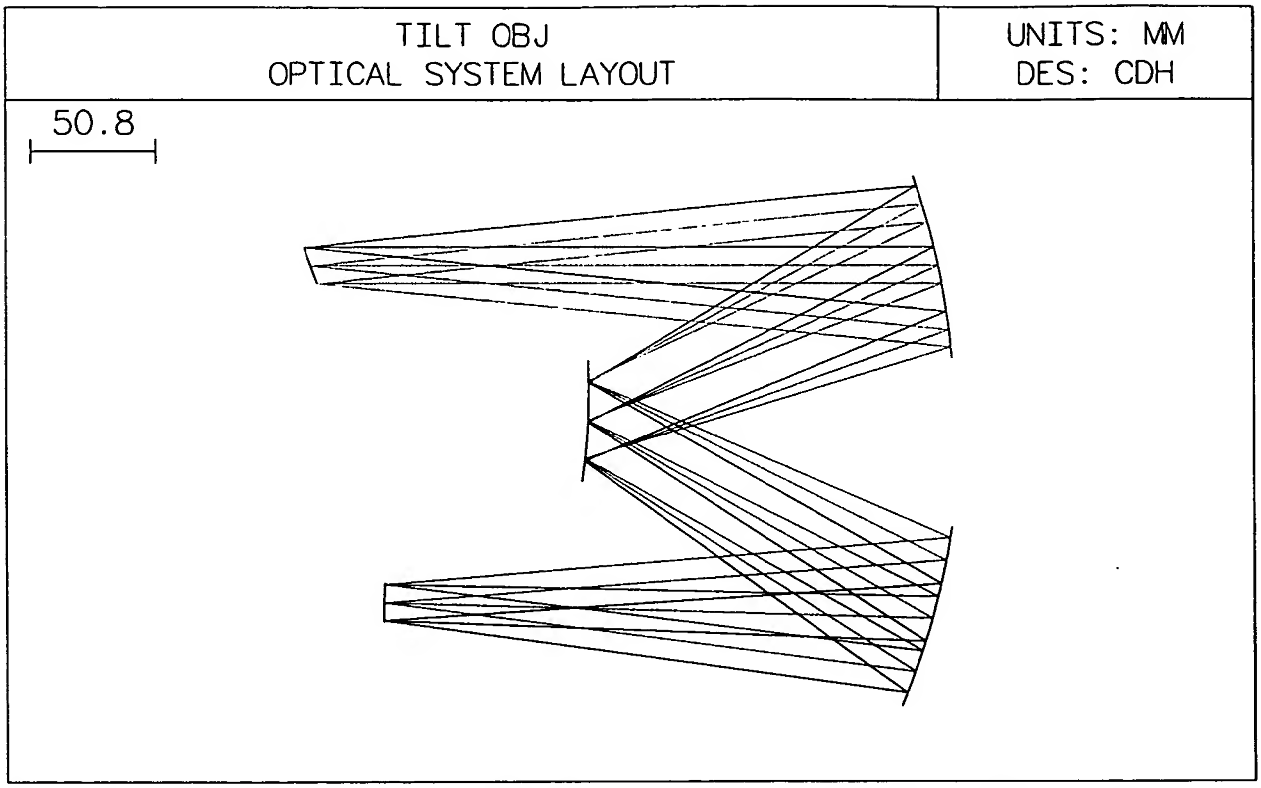


Figure 8. Optimized model of an all reflective image delivery system for a DMD enabled SLM spectral imaging system or imaging system. The object to be imaged onto the DMD is shown at the bottom of the image perpendicular to the optical propagation axis. The design and placement of the relay optical system presents a tilted image appropriate for presentation to the DMD SLM such that the subsequent spatial resolution elements so selected propagate perpendicular the the DMD micro-mirror plane. This allows conventional optical systems to be employed subsequently to the DMD such that image quality is maintained to a high degree of coherence and performance.

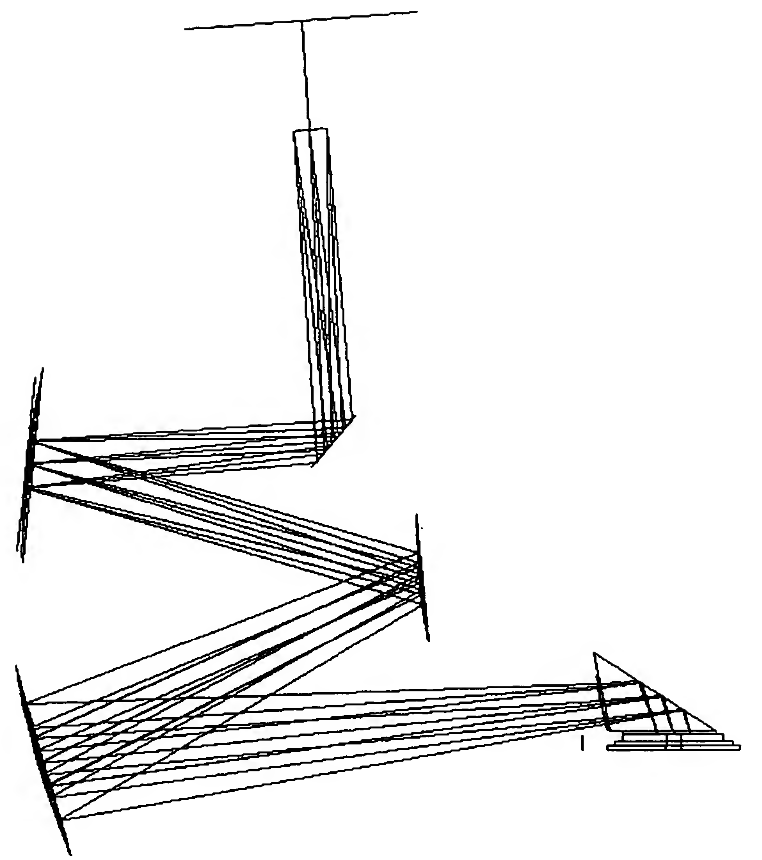


Figure 9. An optical relay system optimized for use with a TIR prism assembly and the DMD SLM such that the tilted image presented to the DMD reflects selected resolution elements perpendicular to the micro-mirror array plane. This allows conventional optical systems such as refractive collimating lenses to be used.

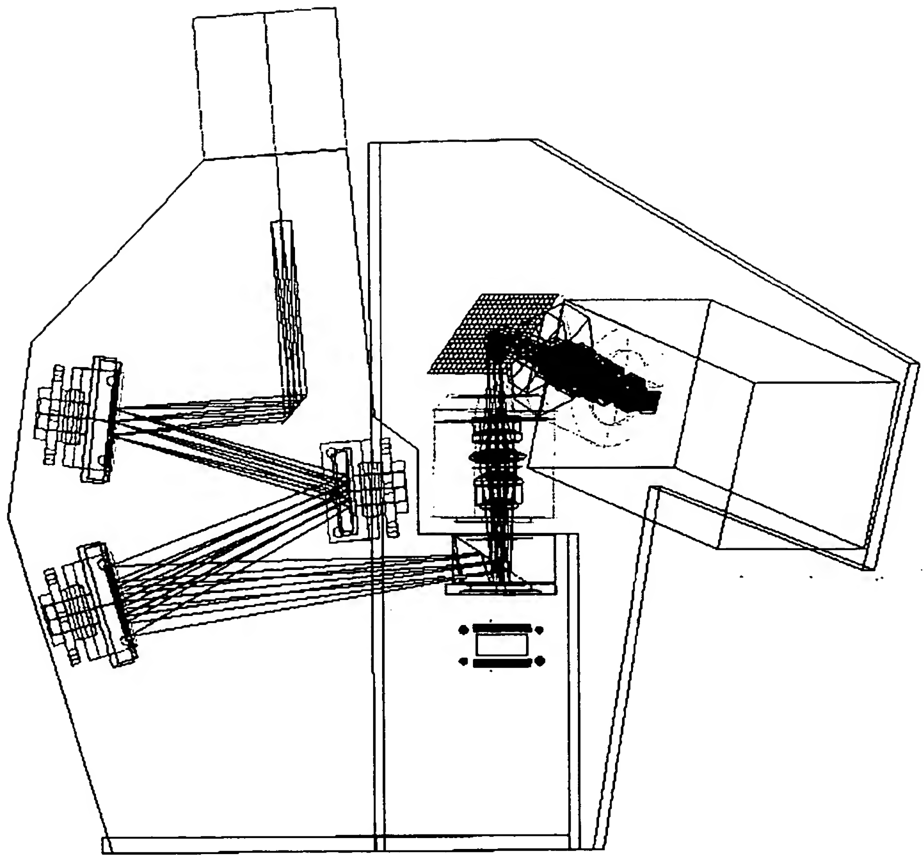


Figure 10.

Figure 11. A solid model of the PSS prototype staring hyperspectral imaging system.

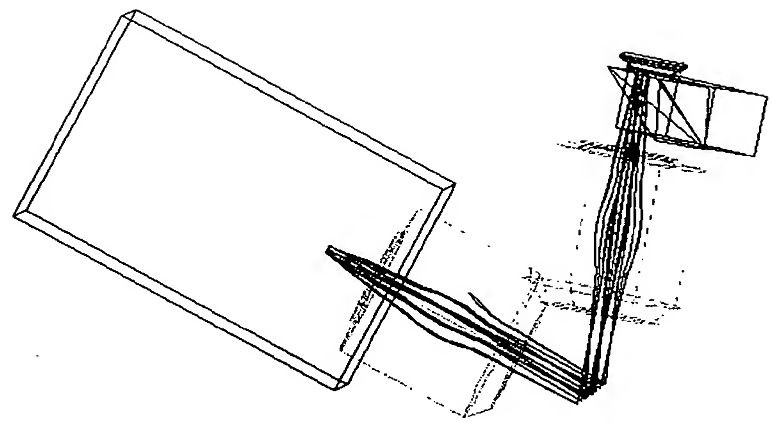


Figure 12. imaging spectrograph in the PSS prototype NSTIS using refractive COTS lens system made for conventional NIR imaging applications.

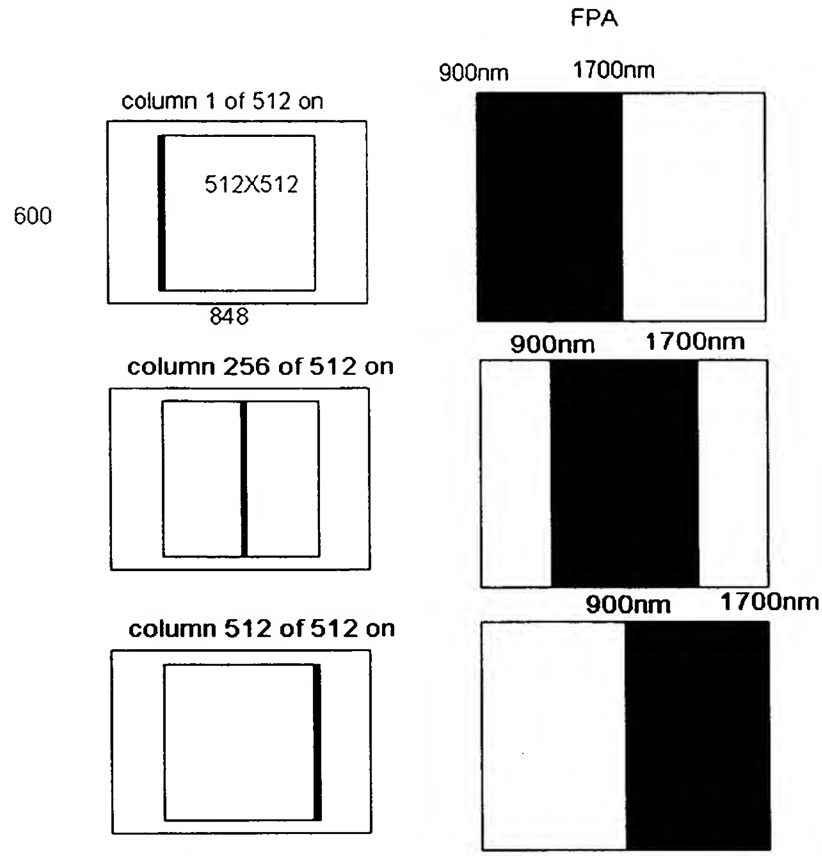
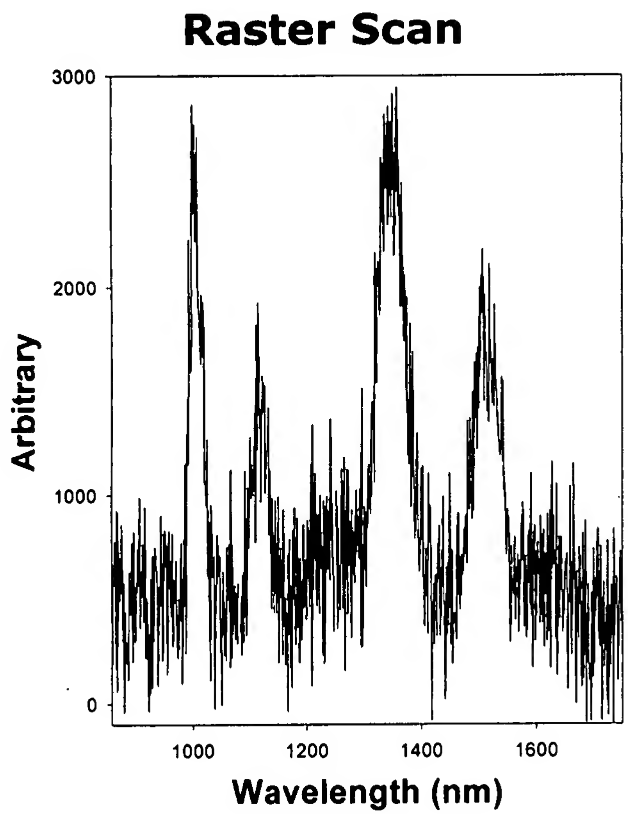
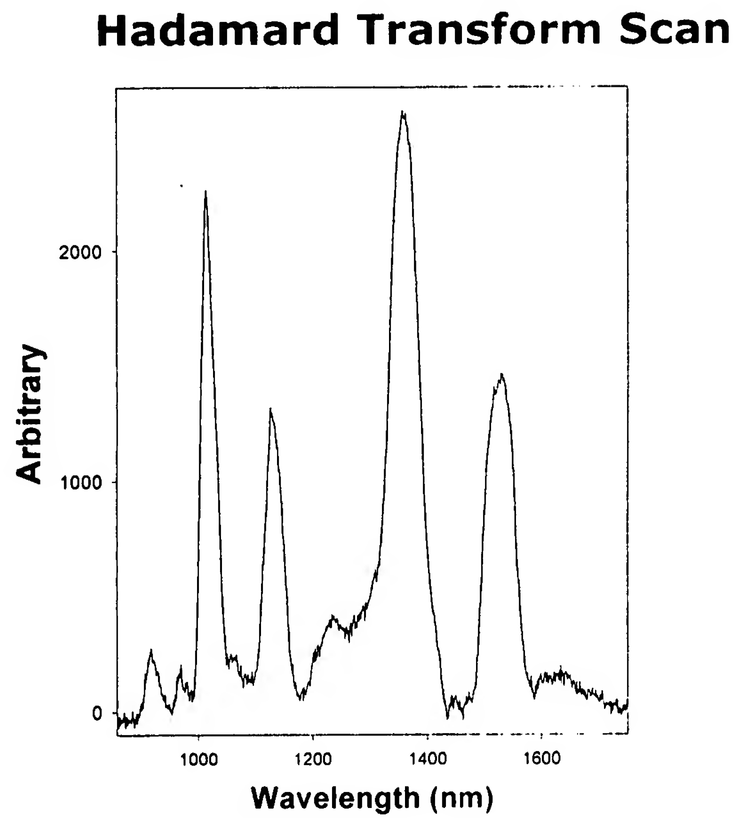


Figure 13, Example of the mapping of micro-mirror columns to the dispersed spectral images at the focal plane of a 2D array sensor, FPA or camera.

Figure 14 Multiplex Advantage





Scans resulting in 800 data resolution elements in the near infrared spectral region of a weak mercury-argon calibration lamp source

Figure 15 Improved Photonic Throughput and Greater SNR

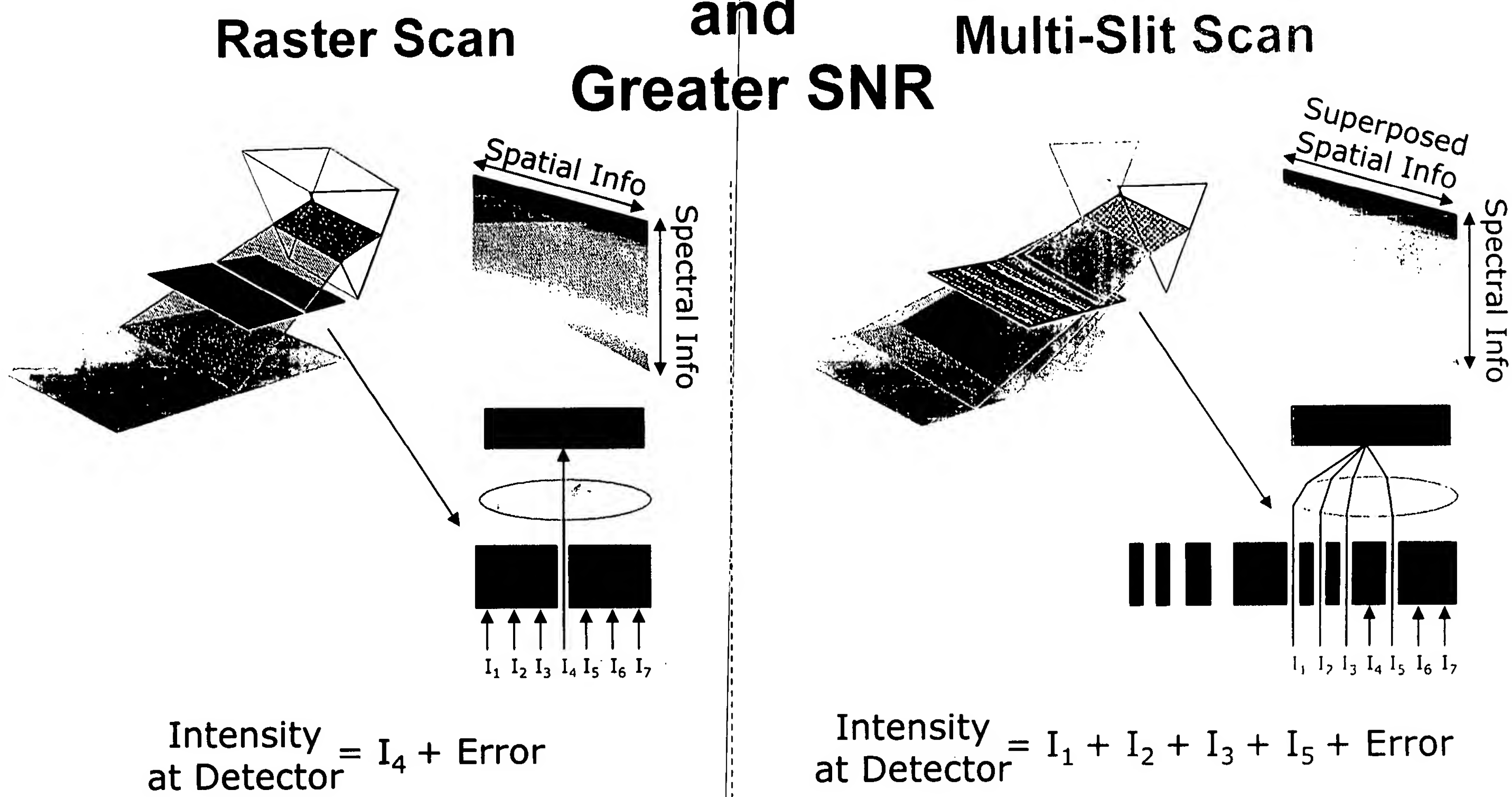
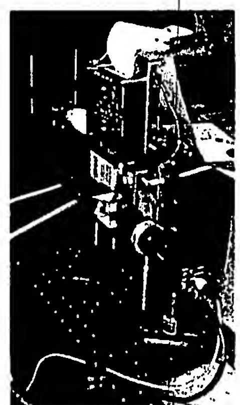


Figure 16 Visible Systems

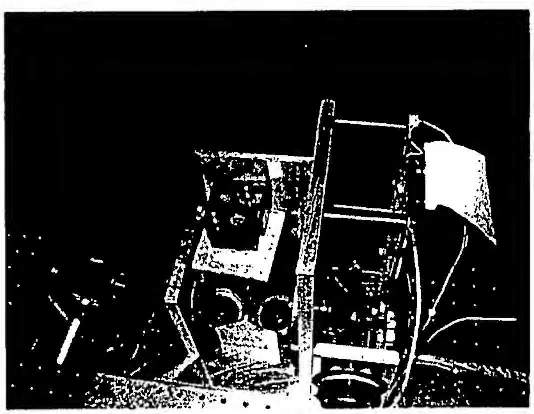
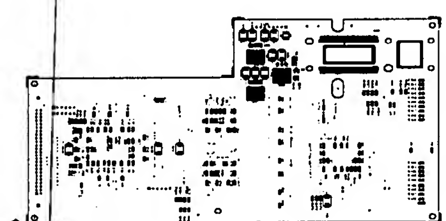




Figure 17 Visible Systems (2)

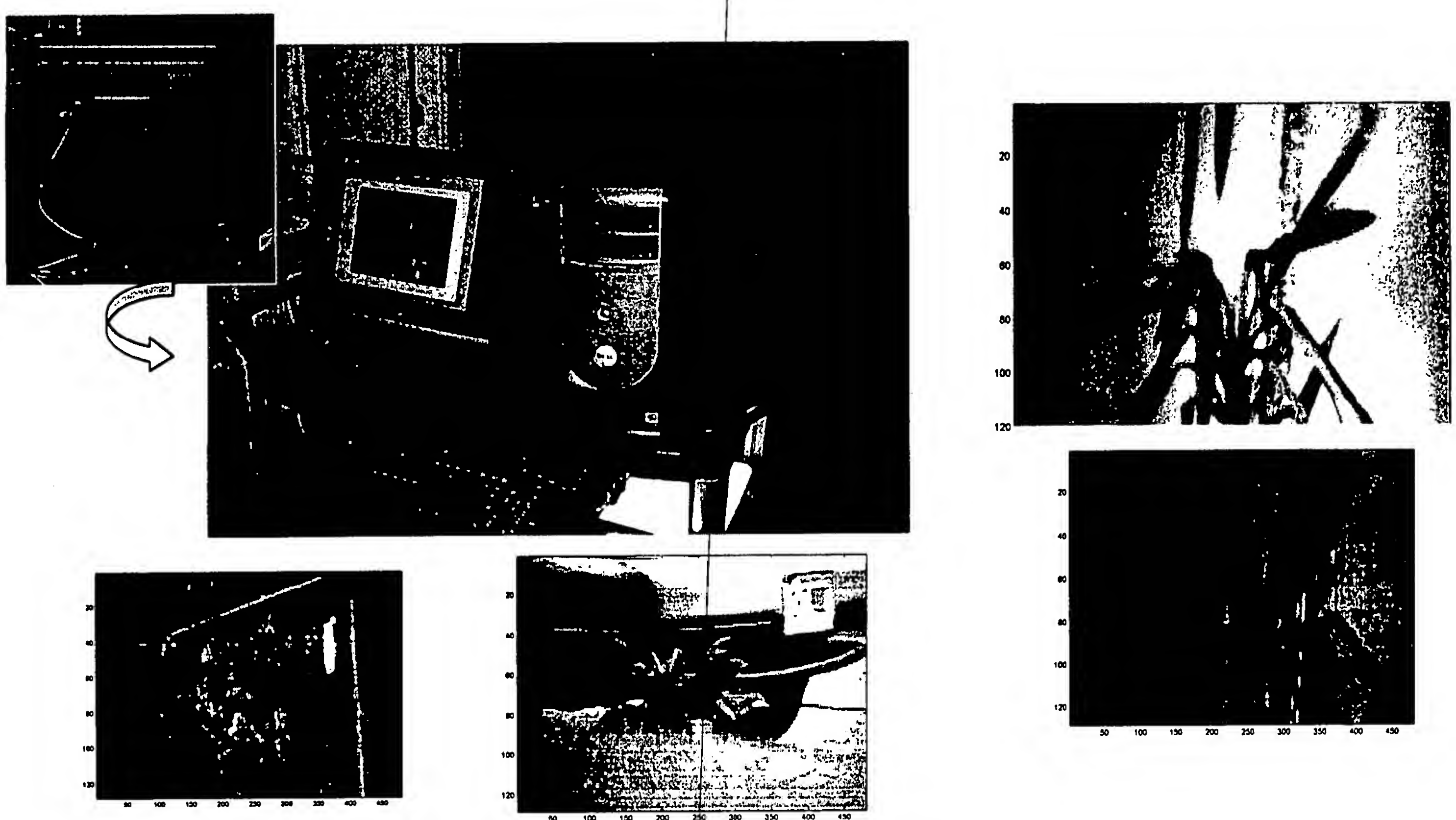
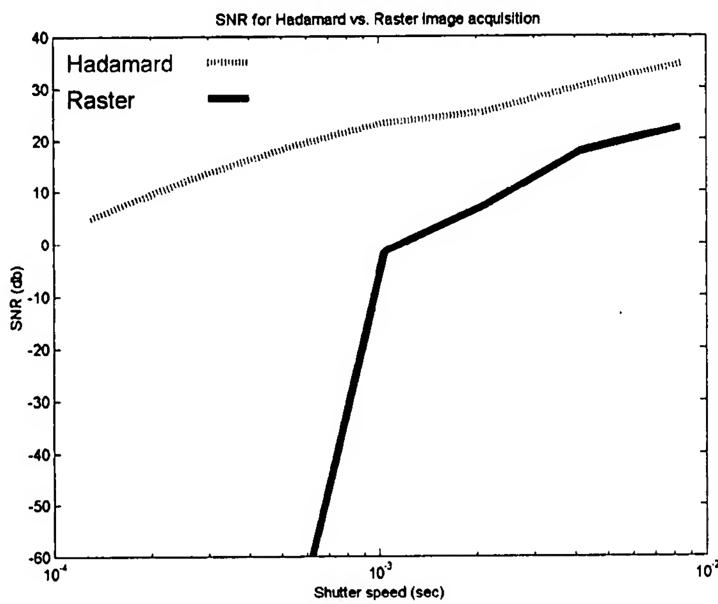


Figure 18: Visible System (3)



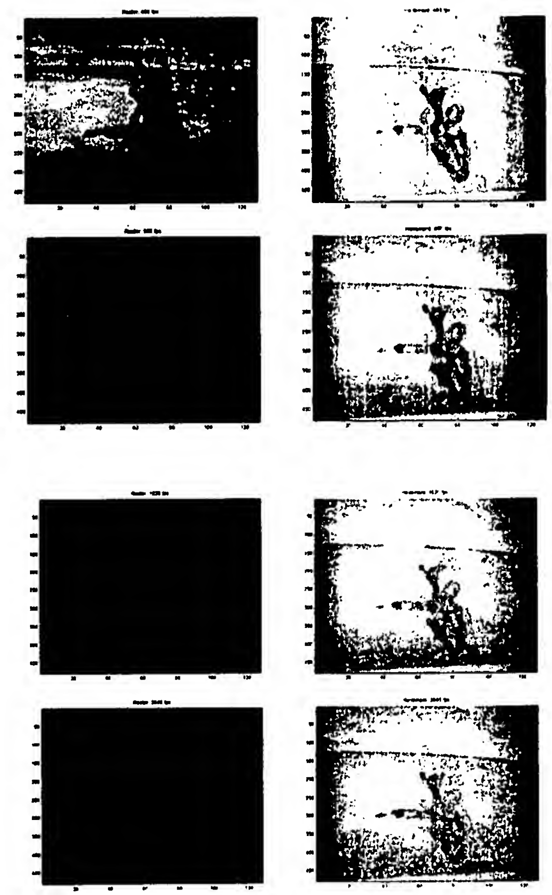
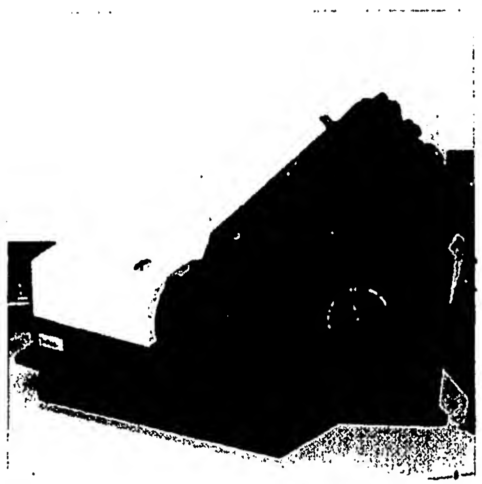


Figure 19: NIR System: Views of NSTIS



Front

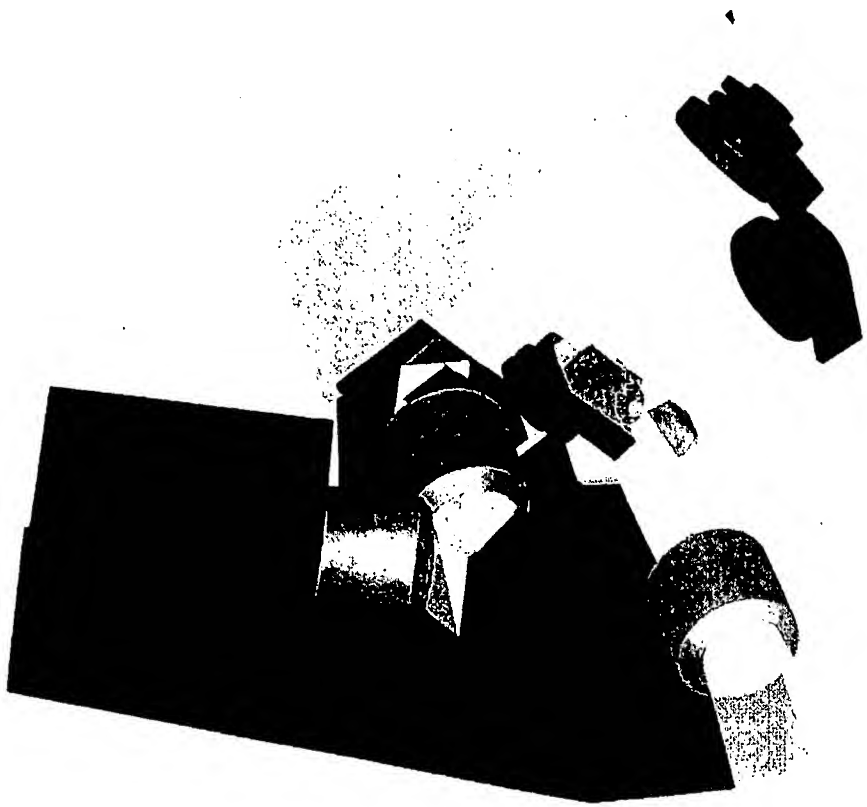
Left Side

Right Side

Figure 20: Sample Data

A scene consisting of a number of different plastics and other materials, imaged with the system and displayed at one wavelength. Spectra of various plastics, as acquired in this dataset, are shown in the following figures. Below are spectra from the scene above, as acquired by the device.

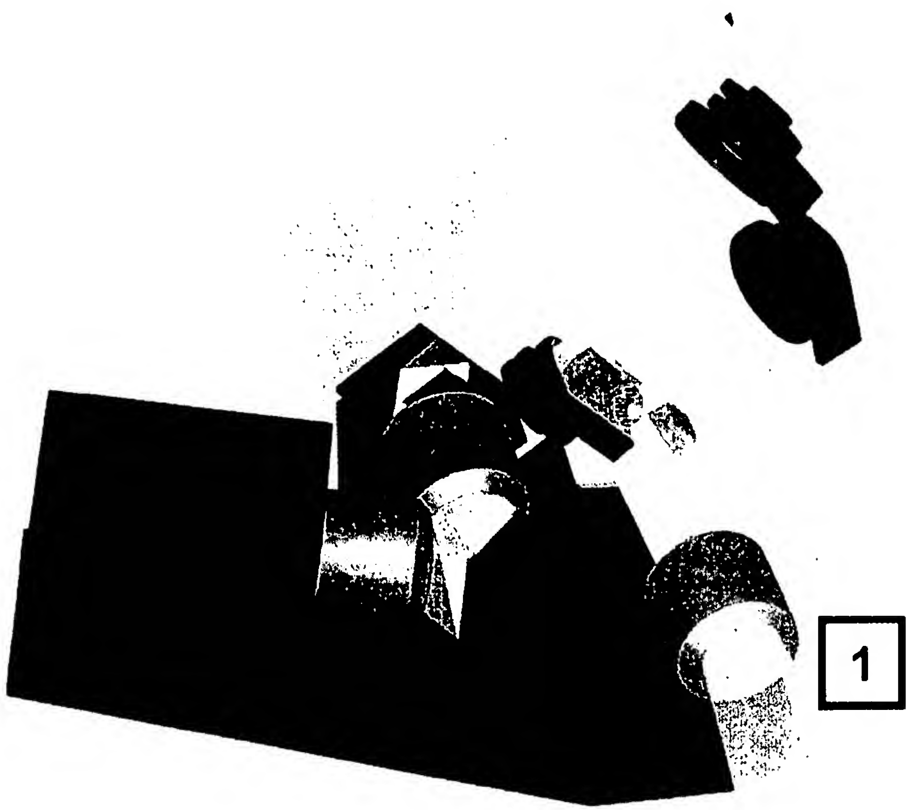
Figure 21



Key Attributes

- NIR Hyperspectral Imaging System
- Modular design, based on COTS parts
- Multiplexed data collection
- No macro-moving parts
- Adaptable Measurement Schemes

Figure 22

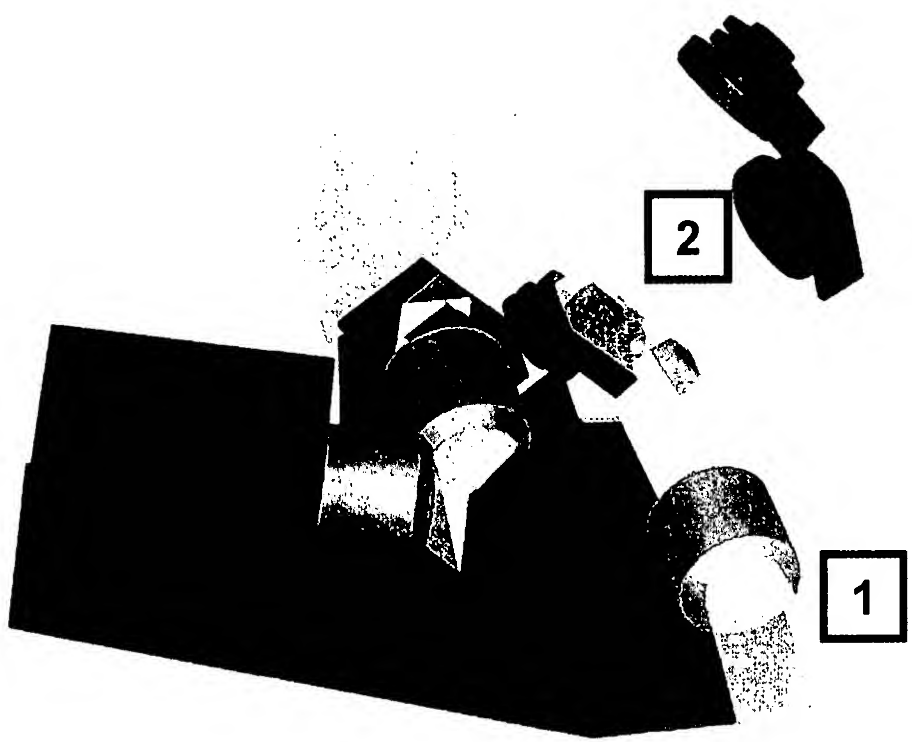


How It Works

1. Camera lens objective

- Standard Cannon mount
- Modular
- Transfers image of a scene into system

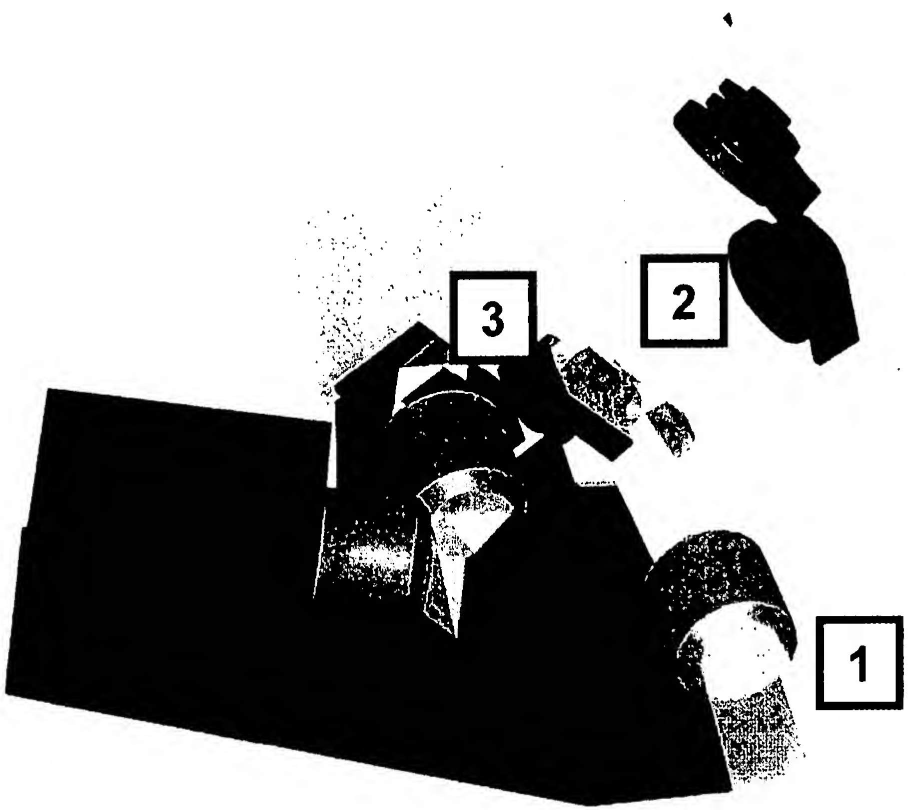
Figure 23



How It Works

1. Camera lens objective
2. All-reflective relay system
   - Transfers image from objective, conditioning it for the DMD
   - Custom PSS system
   - Flat to tilted image plane correction
   - COTS spherical reflectors

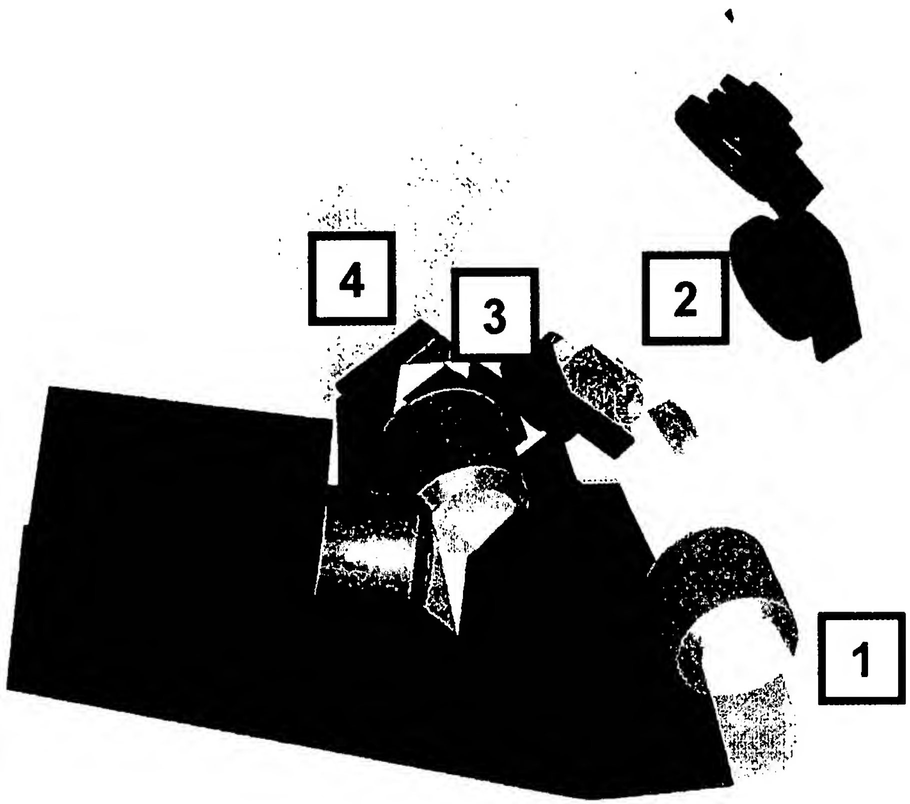
Figure 24



How It Works

1. Camera lens objective
2. All-reflective relay
3. TIR Prism
   - Transfers image onto and off of DMD
   - Folds optical path
   - Custom PSS design for NIR region

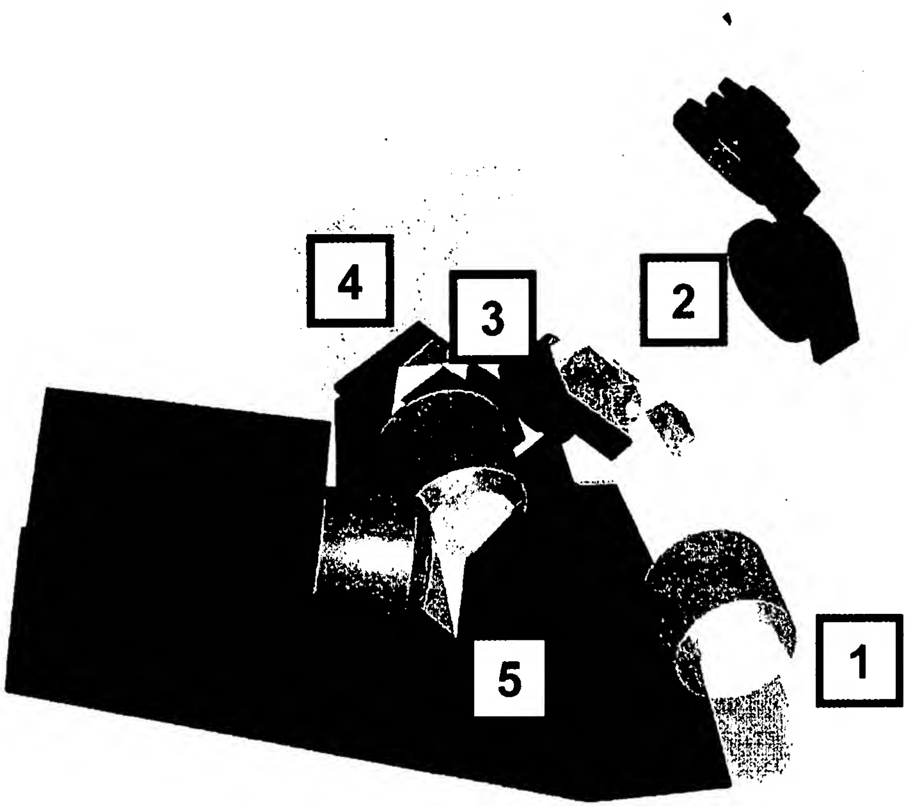
Figure 25



How It Works

1. Camera lens objective
2. All-reflective relay
3. TIR Prism
4. DMD
   - Multiplexing component
   - Modulates system resolution elements
   - COTS TI MEMS mirror array
   - PSS custom controller electronics

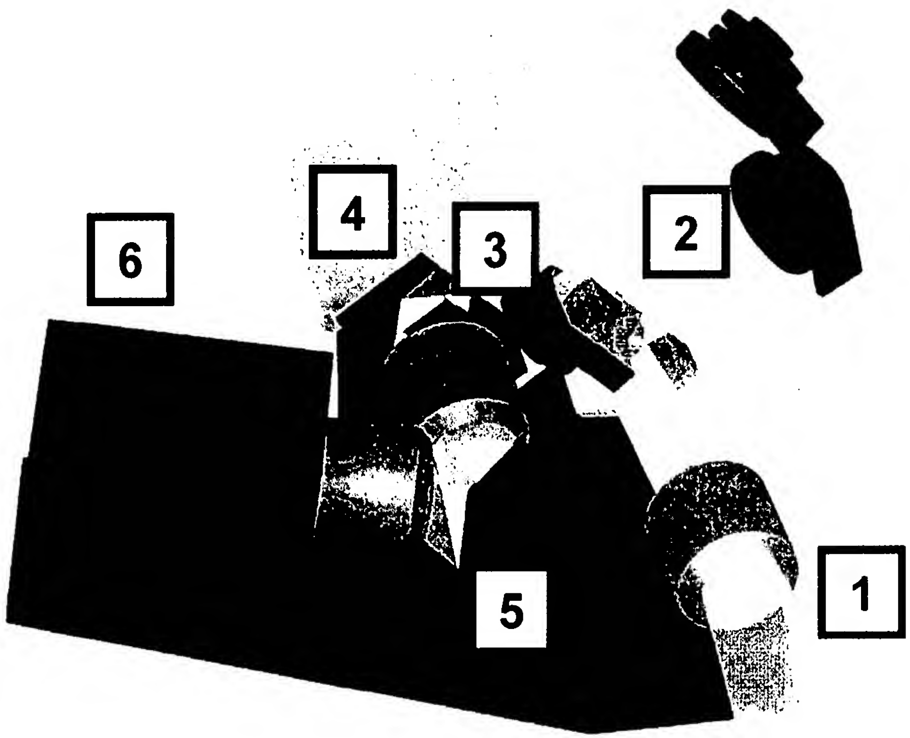
Figure 26



How It Works

1. Camera lens objective
2. All-reflective relay
3. TIR Prism
4. DMD
5. Diffraction Grating
   - Dispersion component
   - Spectrally spreads each "pixel" from the DMD

Figure 27



How It Works

1. Camera lens objective
2. All-reflective relay
3. TIR Prism
4. DMD
5. Diffraction Grating
6. Camera
   - Indigo Phoenix NIR camera
   - 900nm – 1700nm
   - 640 x 512 pixels

Figure 28 - NSTIS Optical Path and

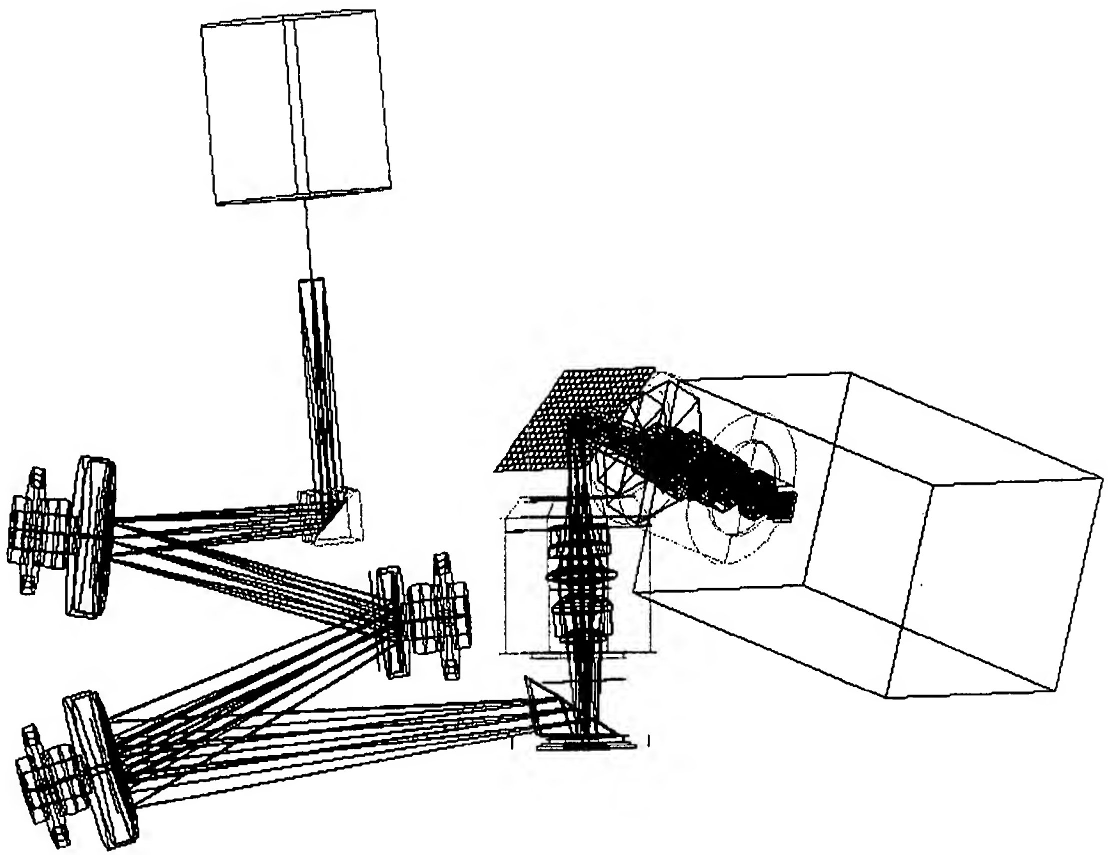
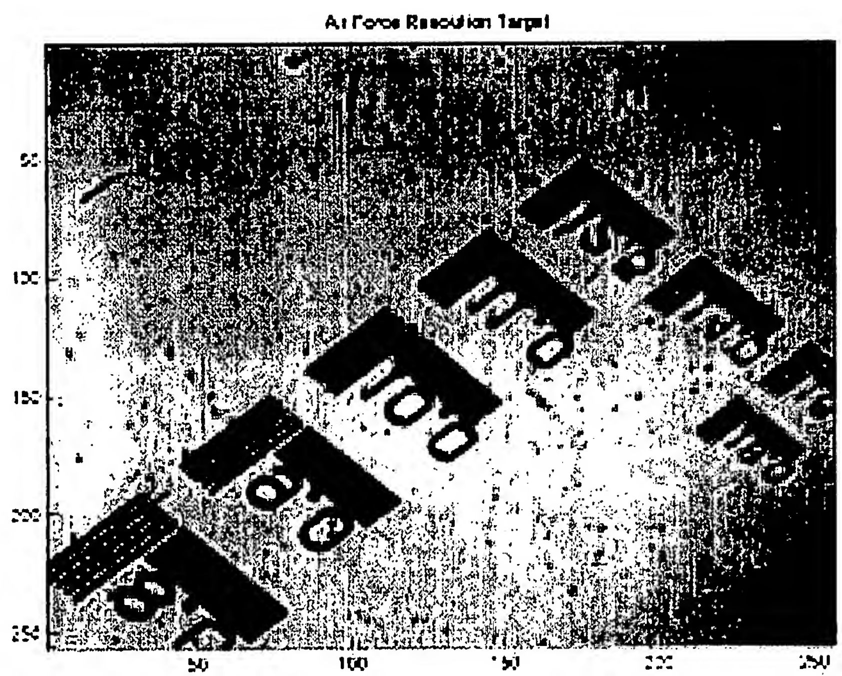
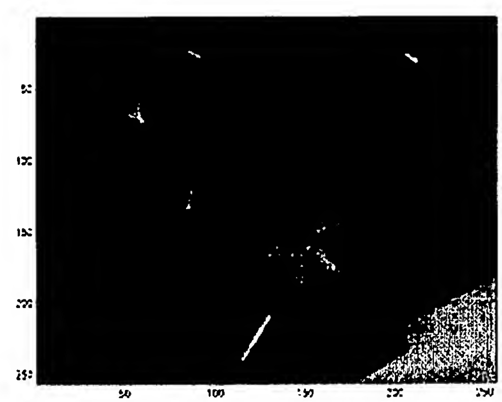


Figure 29 - Air Force Resolution Target imaged with the system



This target was placed at the image plane of the optical system. It is shown at one wavelength to demonstrate resolution.

Figure 30 - Nstis Data Example Revisited



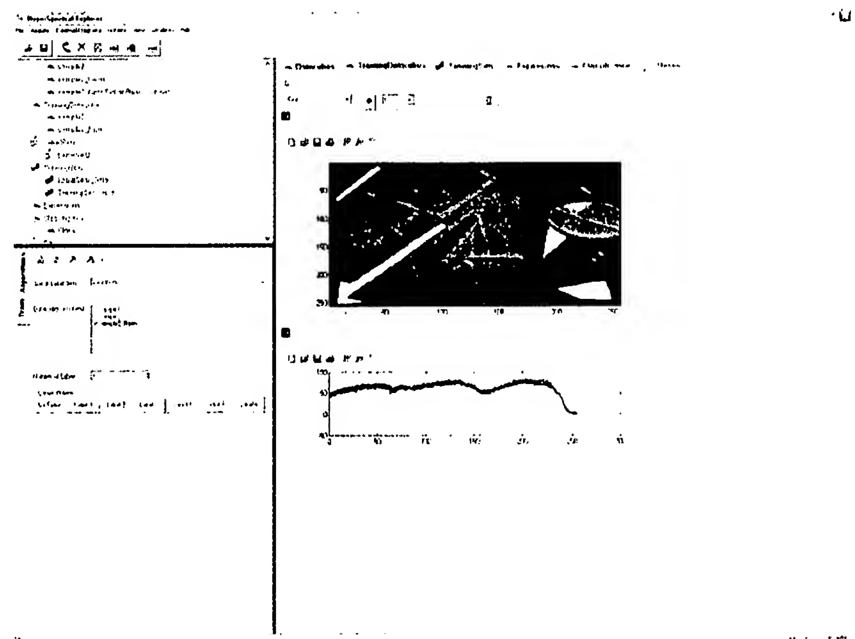


Figure 31

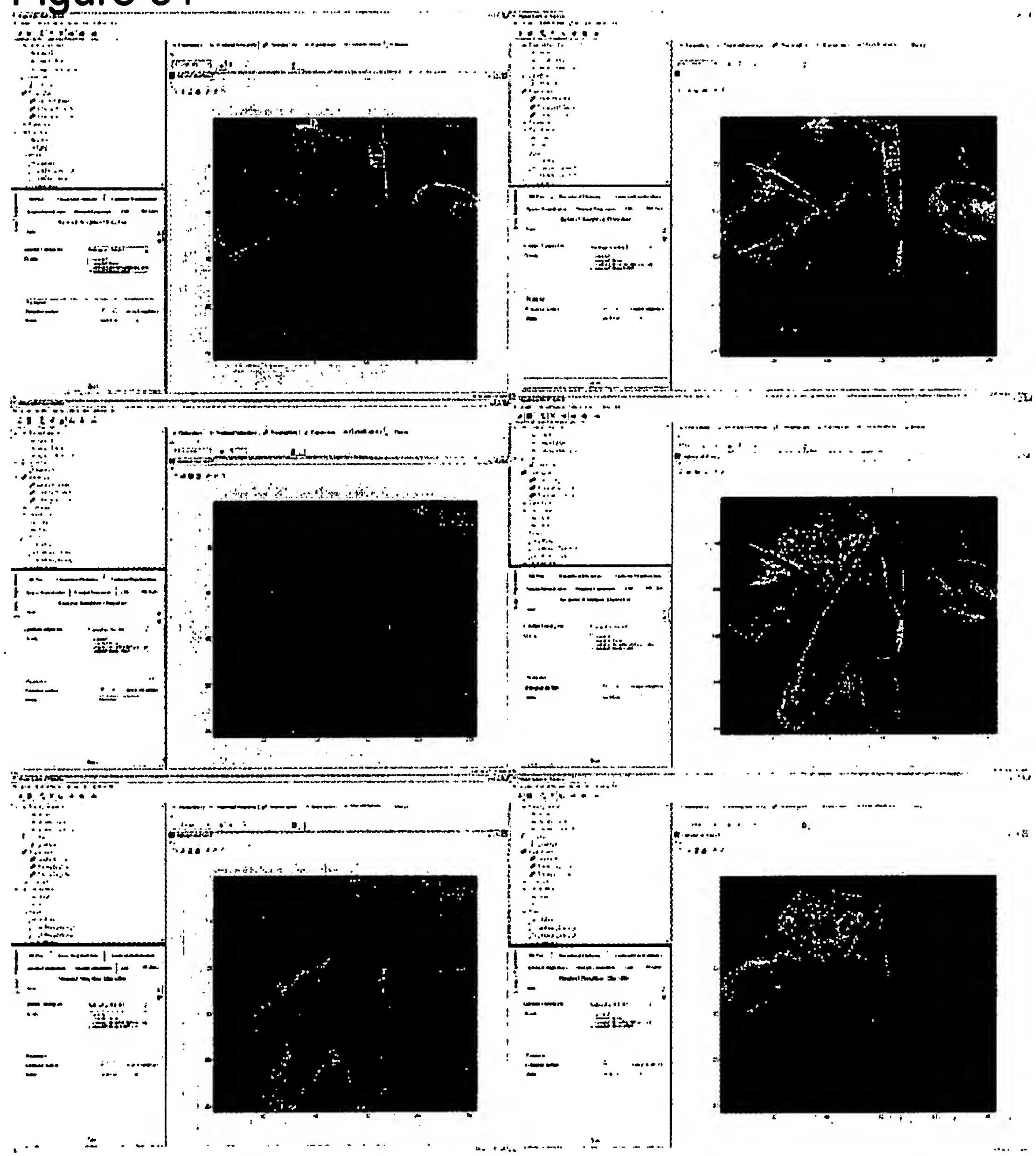
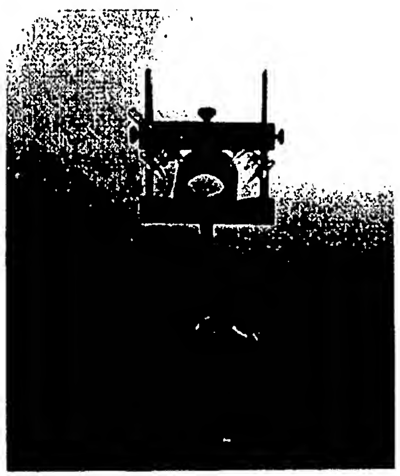
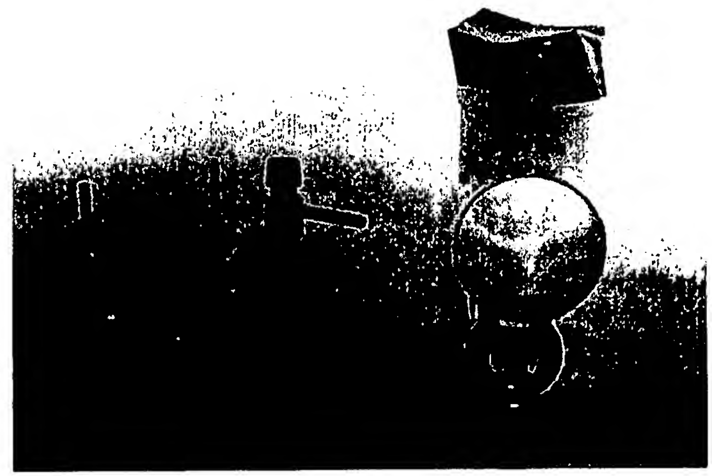
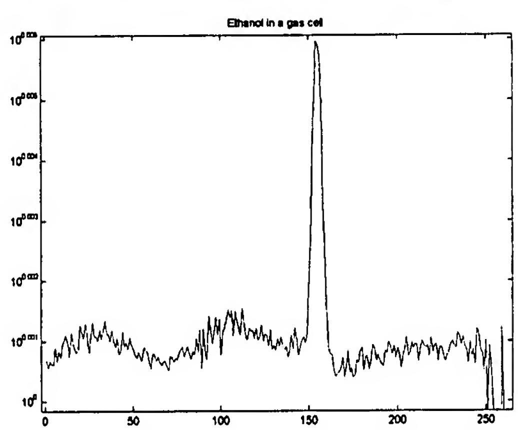


Figure 32 More NSTIS Data







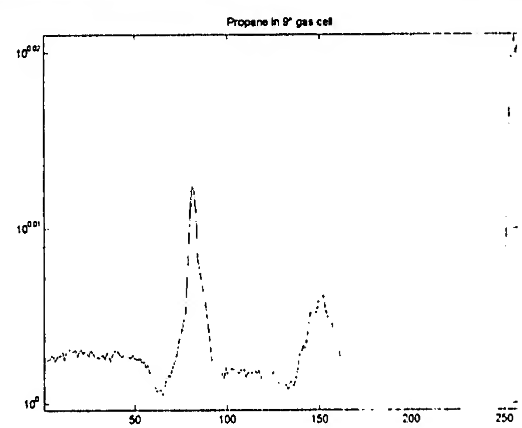


Figure 33 - More NSTIS Data

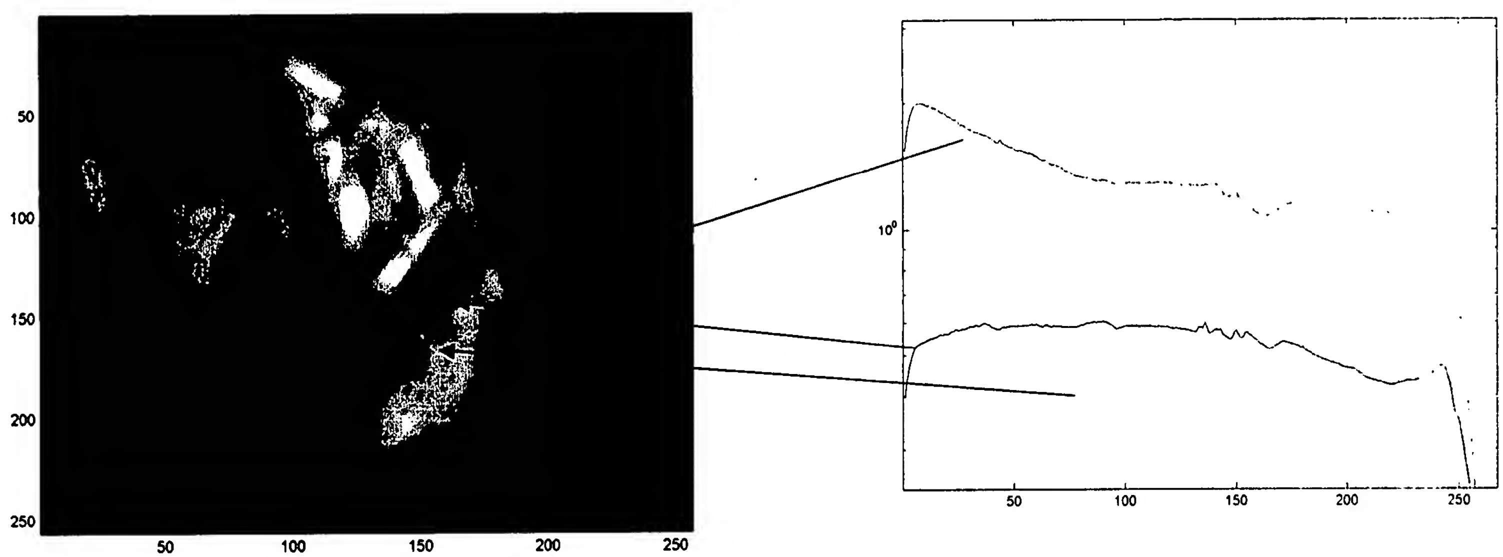
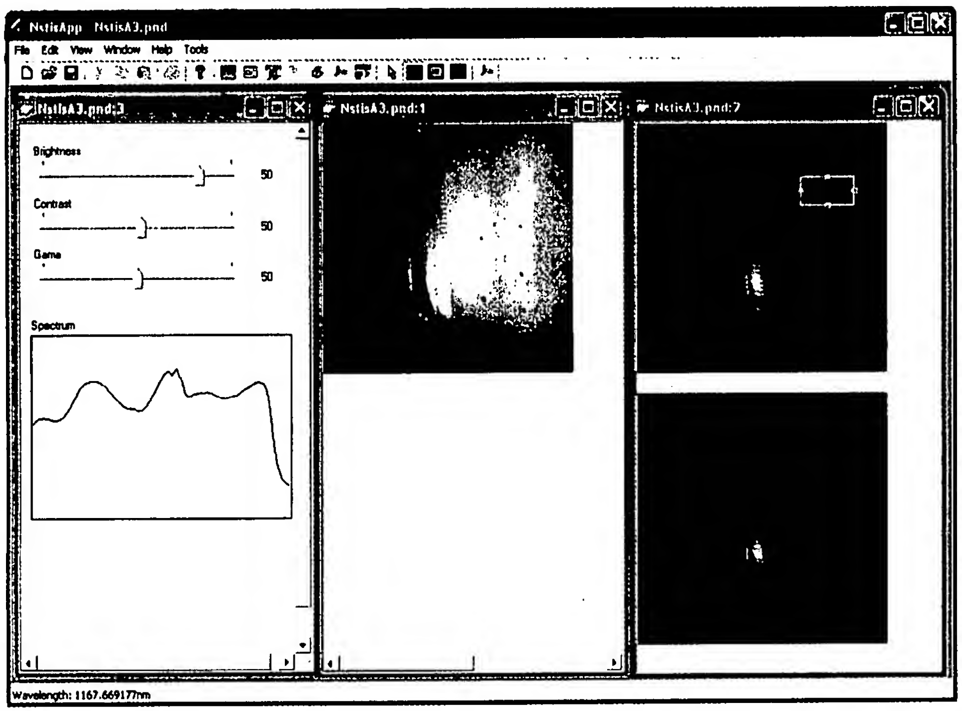


Figure 34 - NstisApp



- Simple GUI for datacubes
- Preview, Acquire, View, Store and Load
- Advanced processing elsewhere

Figure 35

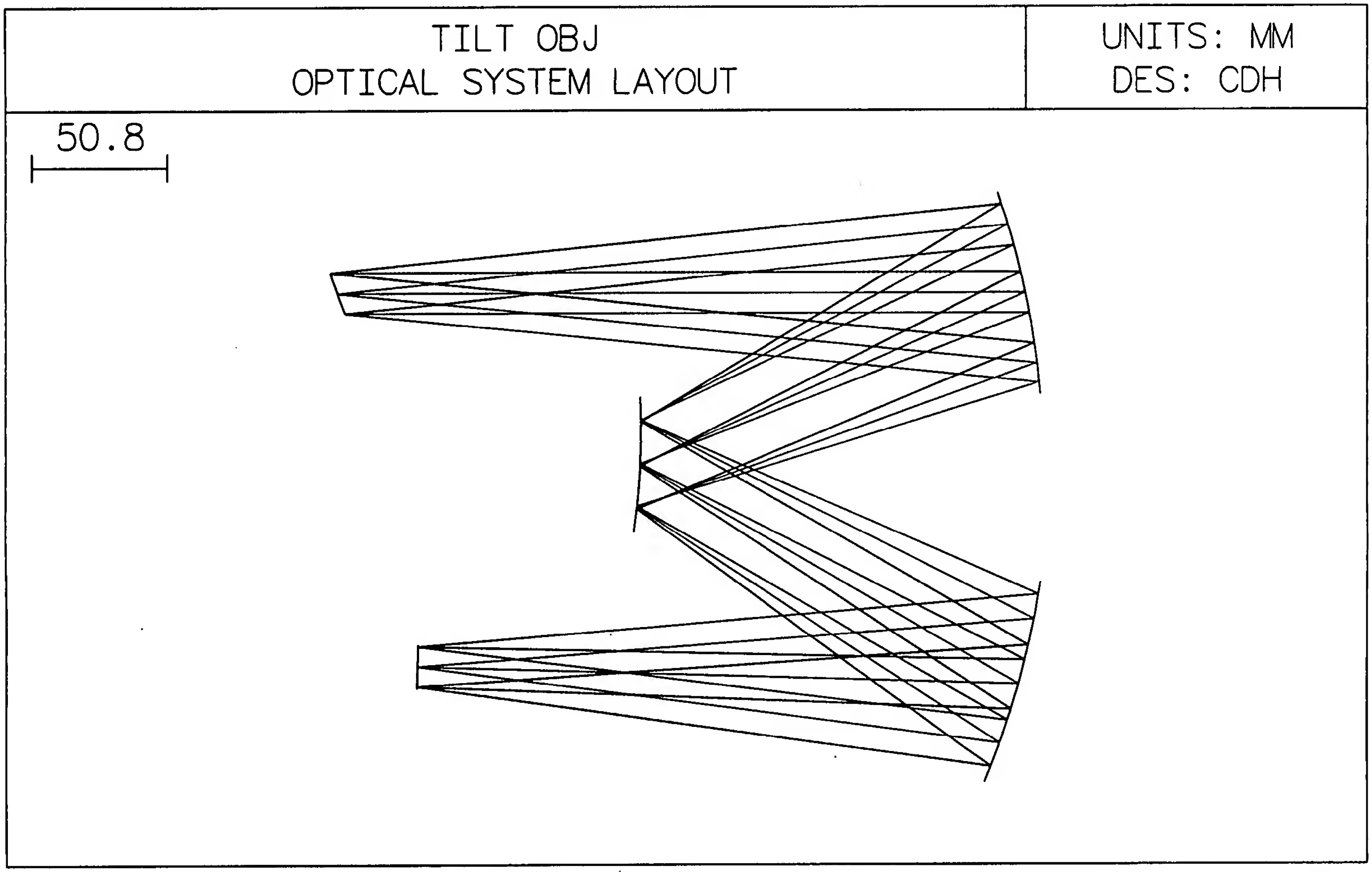
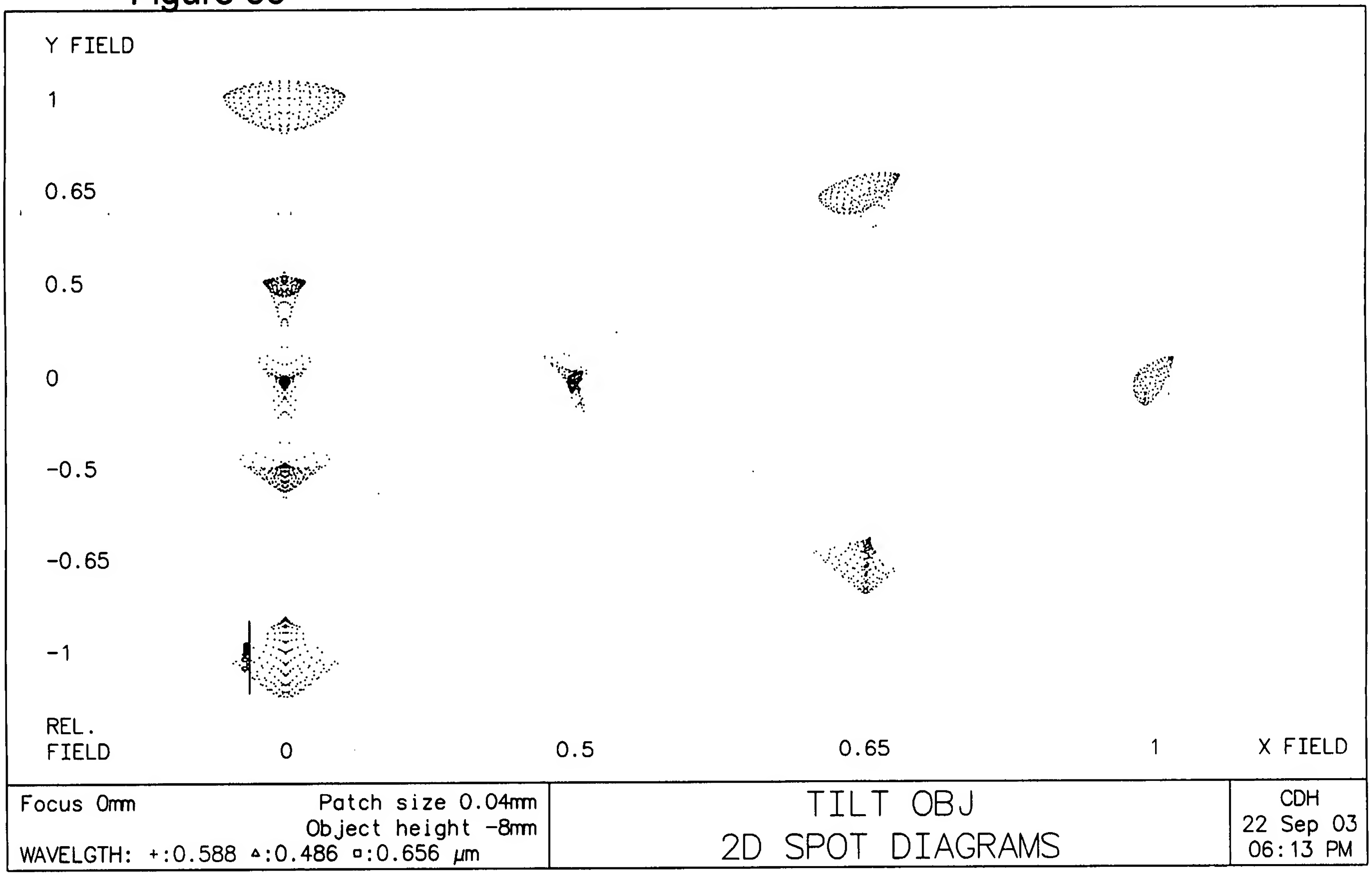


Figure 36



Y FIELD
1
0.65
0.5
0
-0.5
-0.65
-1
REL.
FIELD
0
0.5
0.65
1
X FIELD
Focus 0mm
Patch size 0.04mm
Object height -8mm
WAVELGTH: +:0.588 △:0.486 □:0.656 µm
TILT OBJ
2D SPOT DIAGRAMS
CDH
22 Sep 03
06:13 PM

Figure 37: DMD: Digital Micro-Mirror

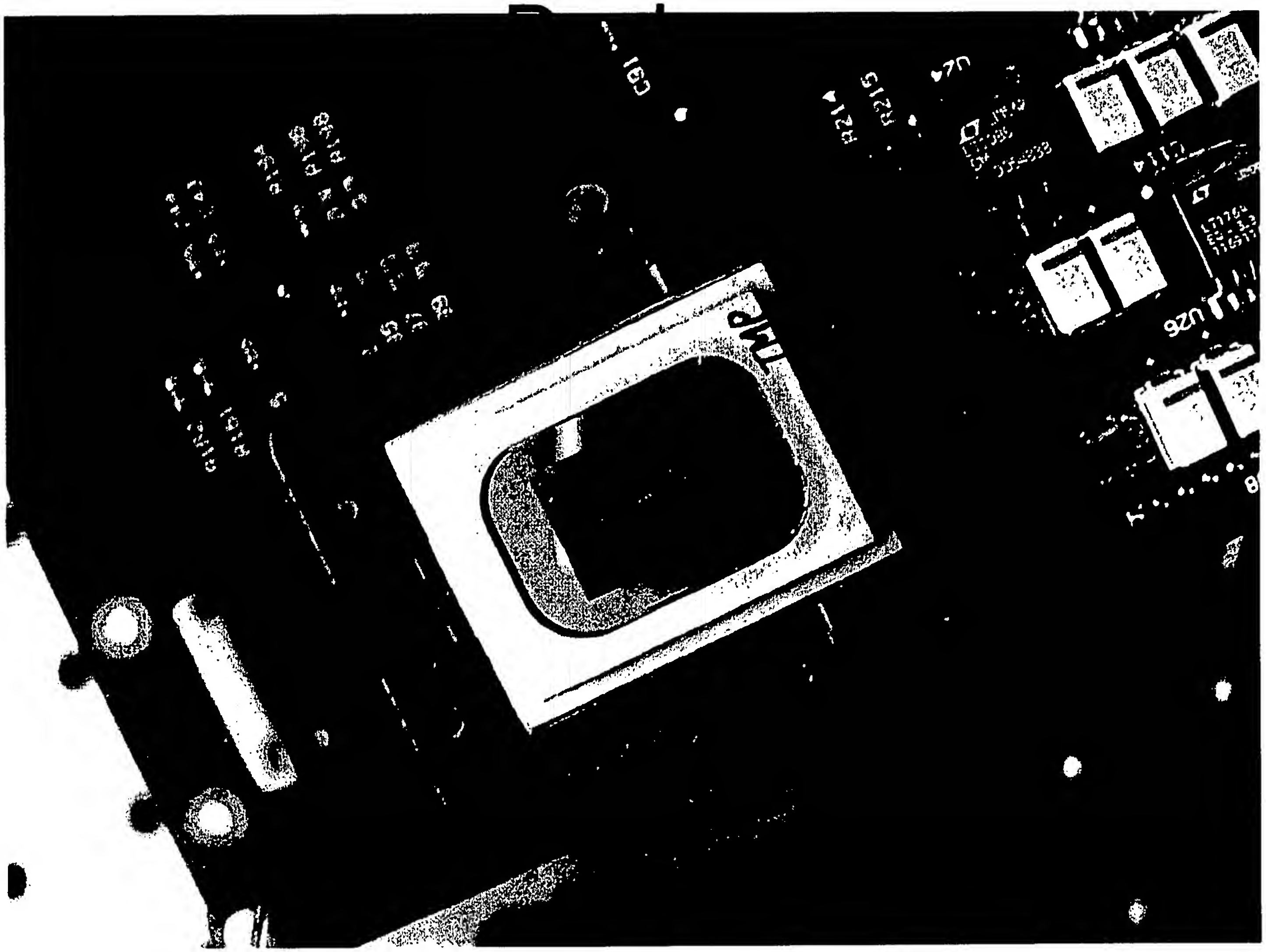


Figure 38: DMD: Up Close

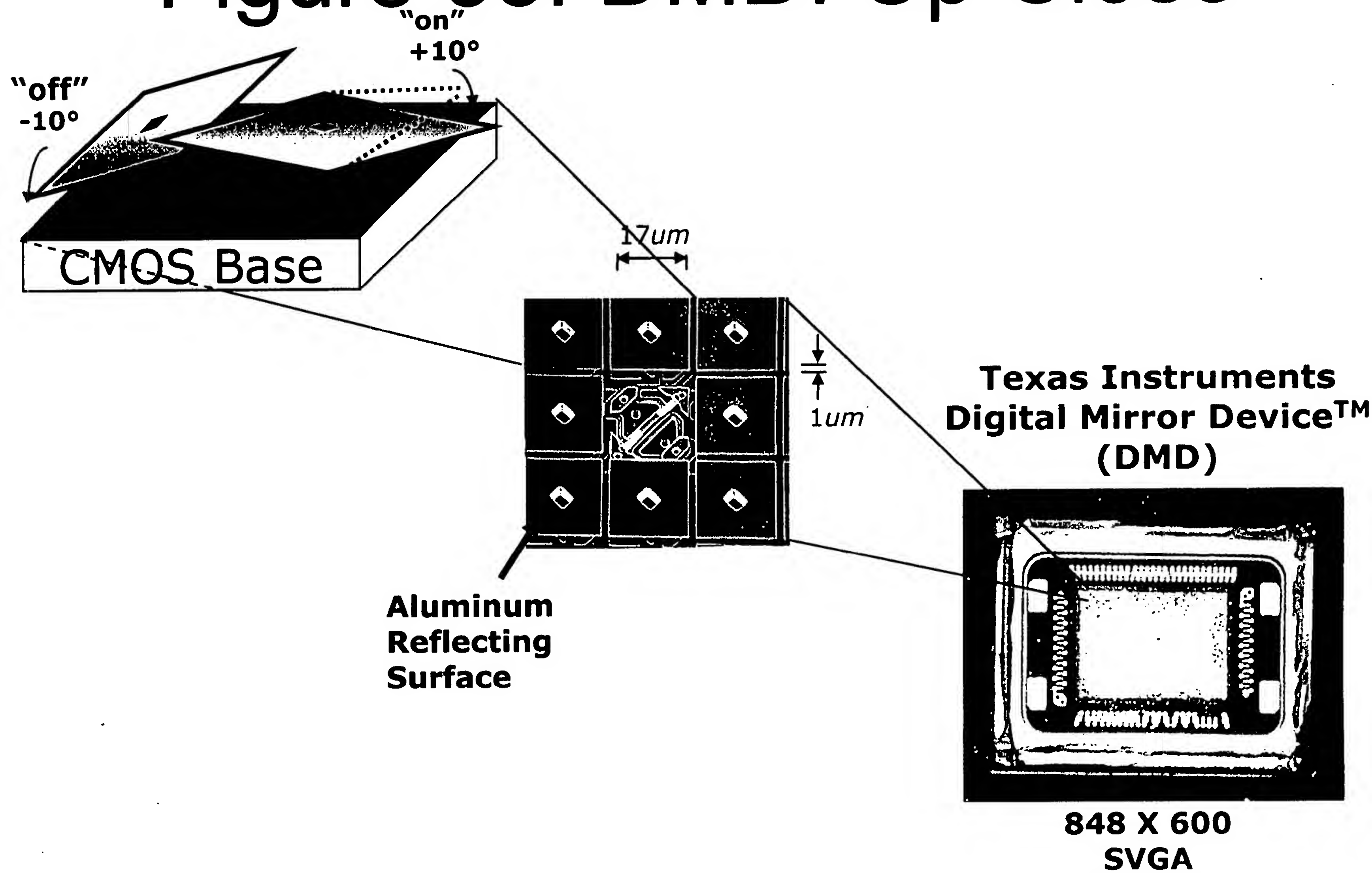


Figure 39: DMD: The DMD and Spectroscopy

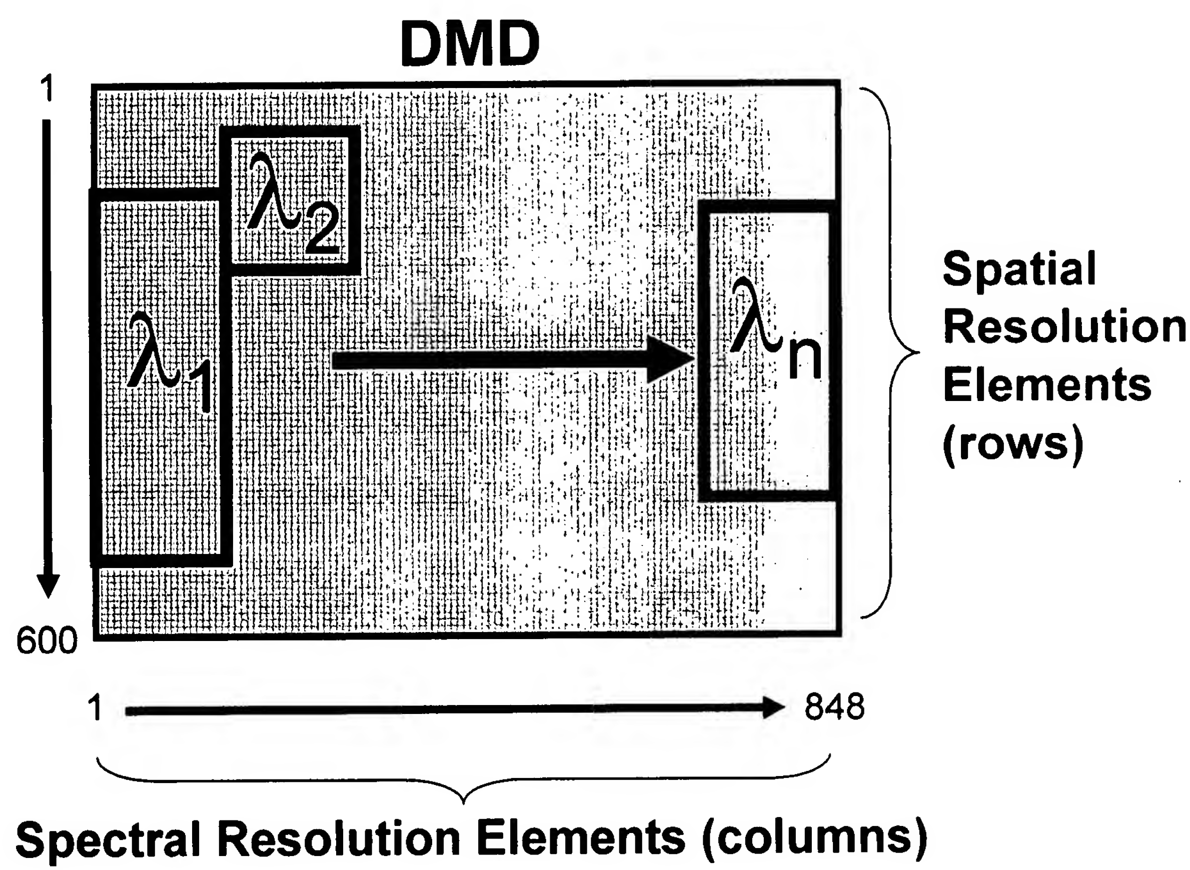


Figure 40: Vis-NIR Hyperspectral Camera

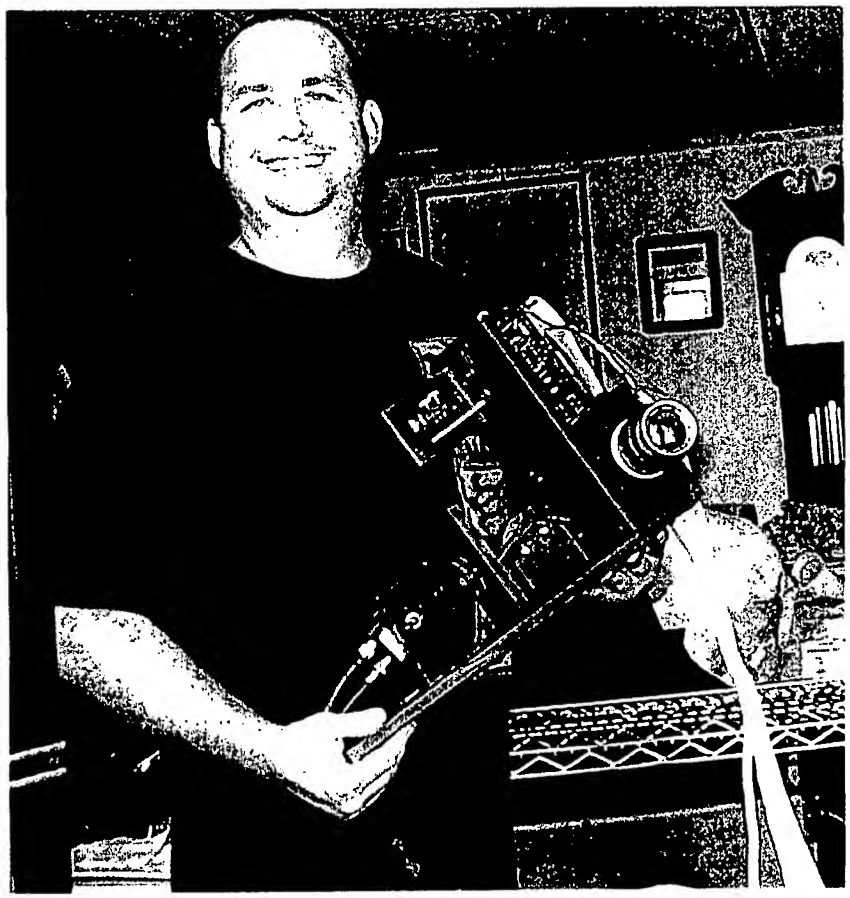


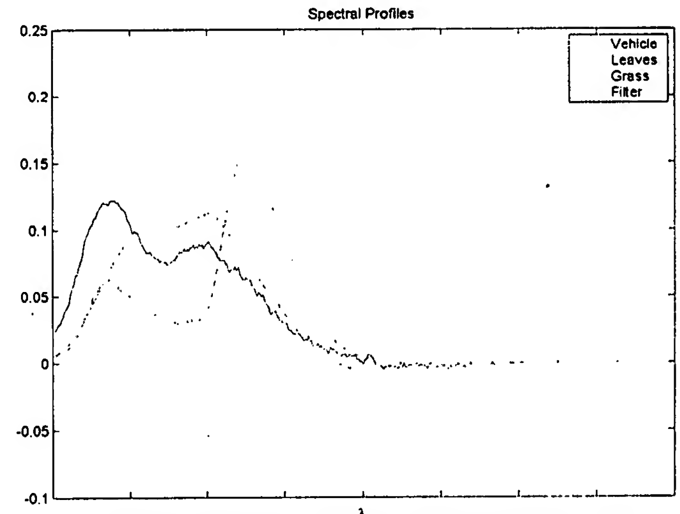
Figure 41: Vis-NIR: Hyperspectral Imaging

RGB Camera Image

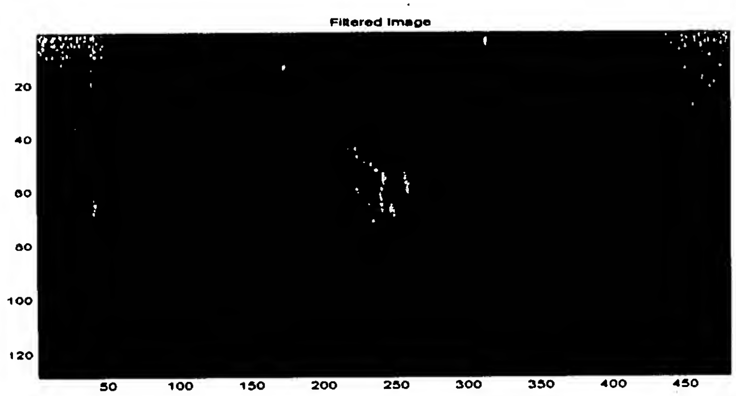
False Color Image

Fig 42: Vis-NIR: Camouflage Detection

RGB Camera Image



Spectral Signatures of Constituent Elements



Filtered Image

Orthogonal Processing of Target vs. Background

Fig 43 - NSTIS: Near-Infrared Spectral Target Identification System

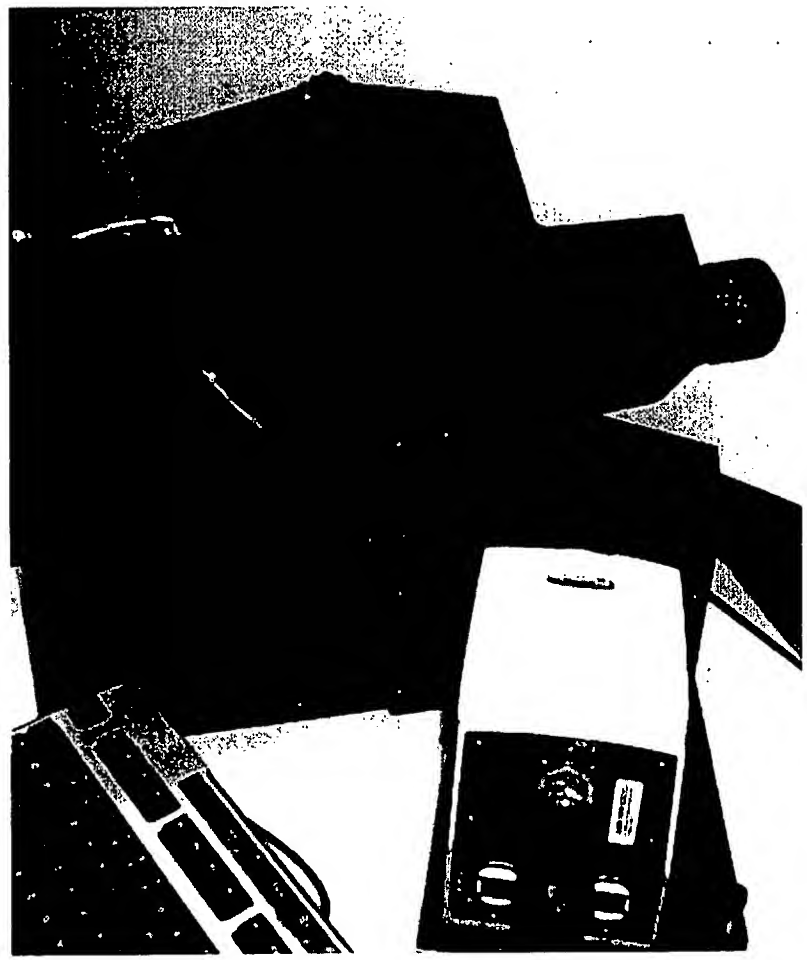


Fig 44: NSTIS: Scene Spectral Components

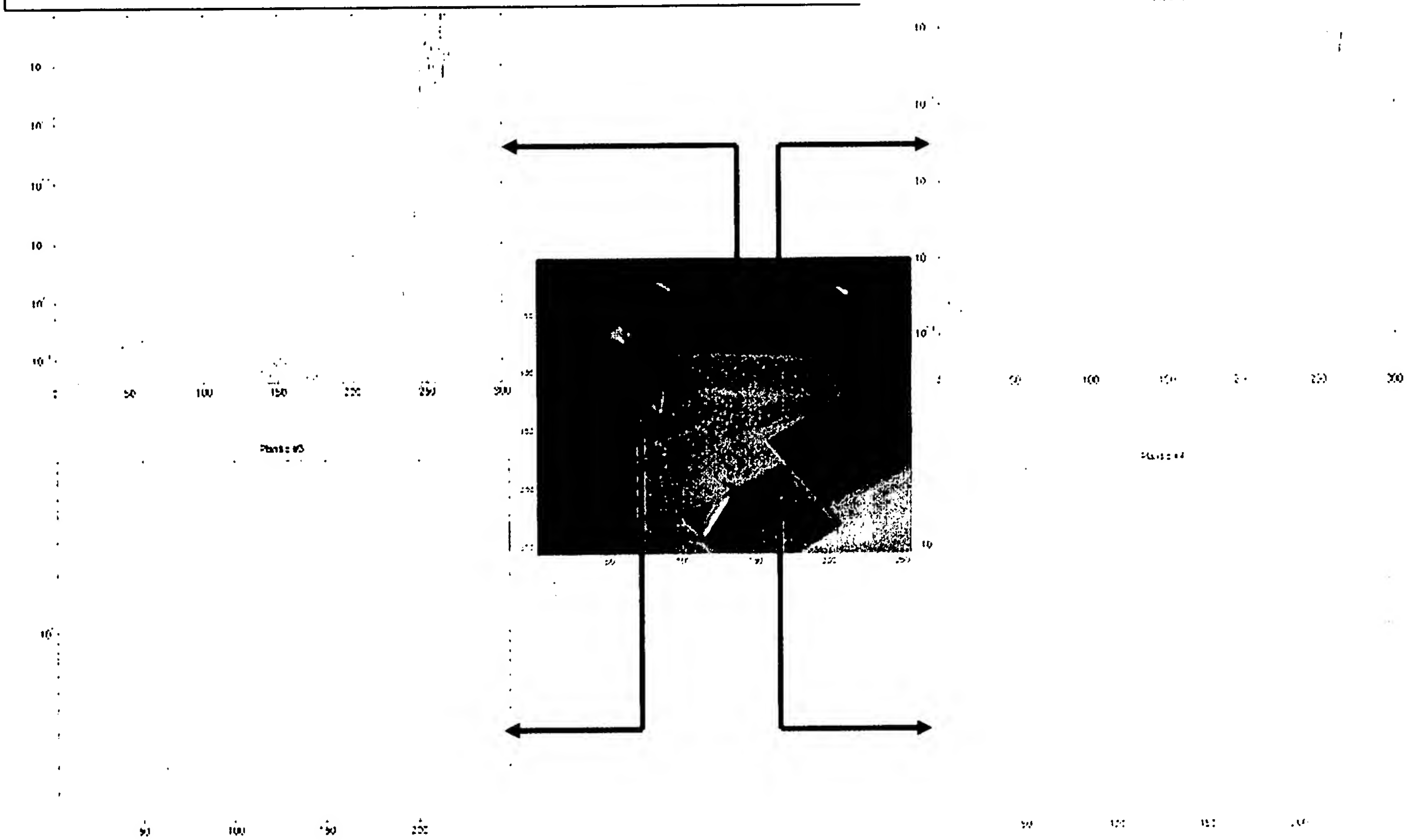
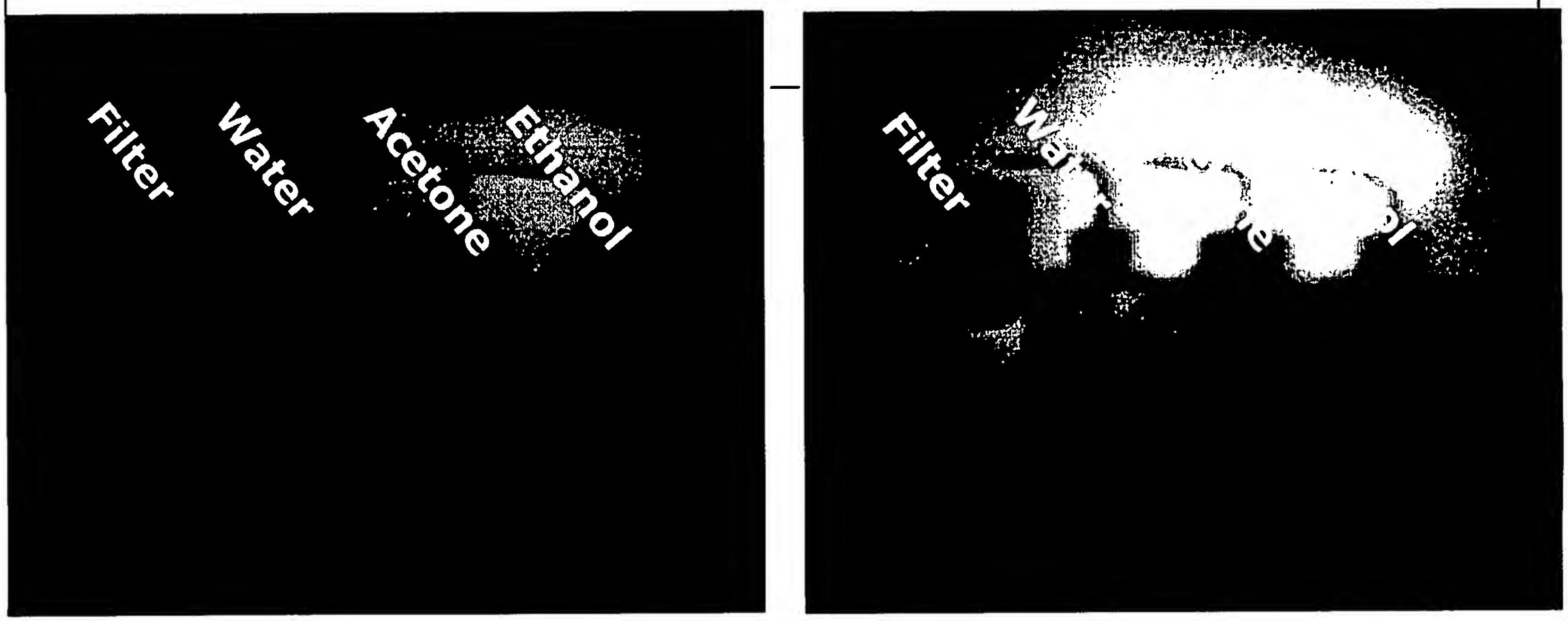


Fig 45: NSTIS: Identification



Left to right: 1064nm filter, Water, Acetone, Ethanol shown here at two different wavelengths

Fig 46: HSE: HyperSpectral Explorer

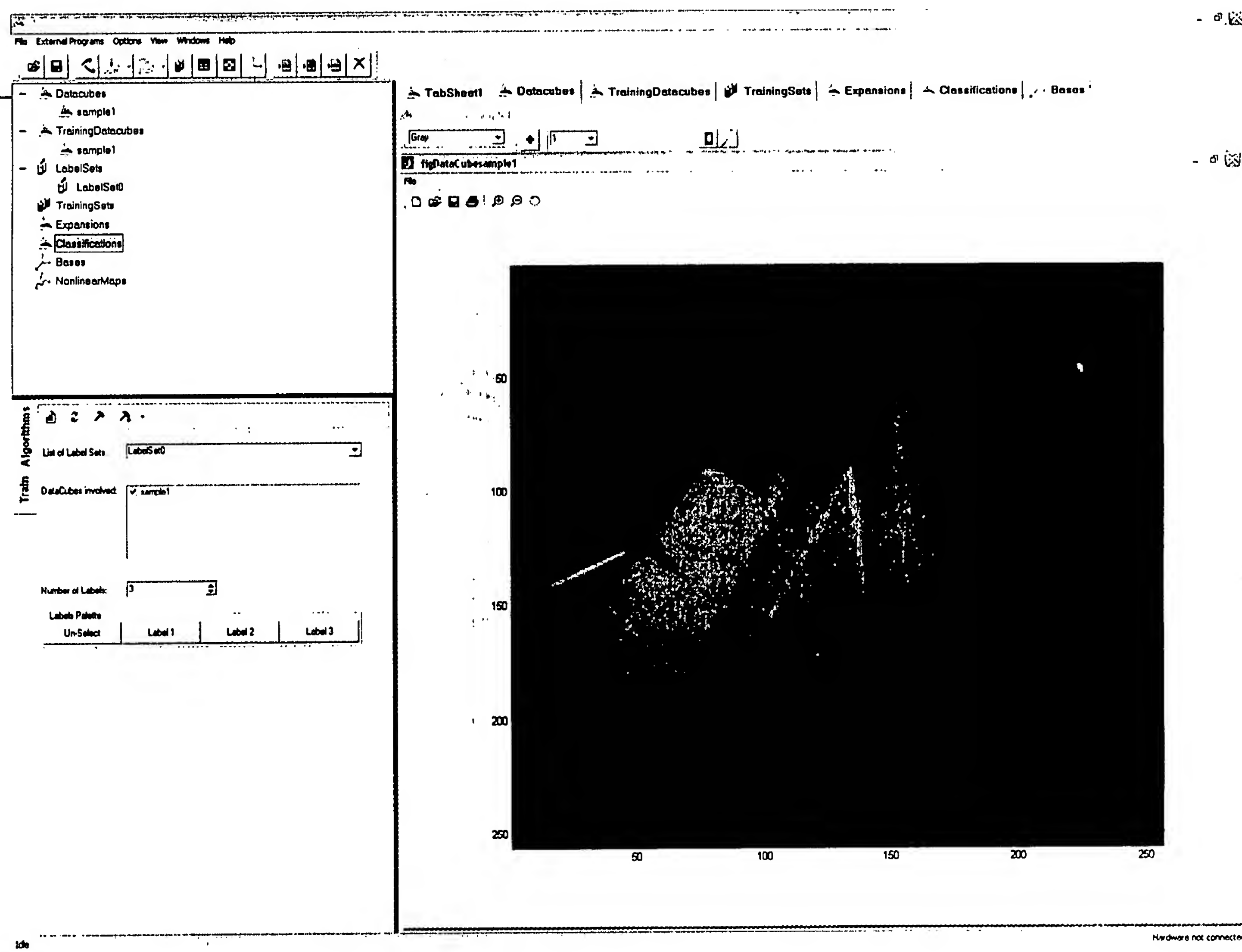
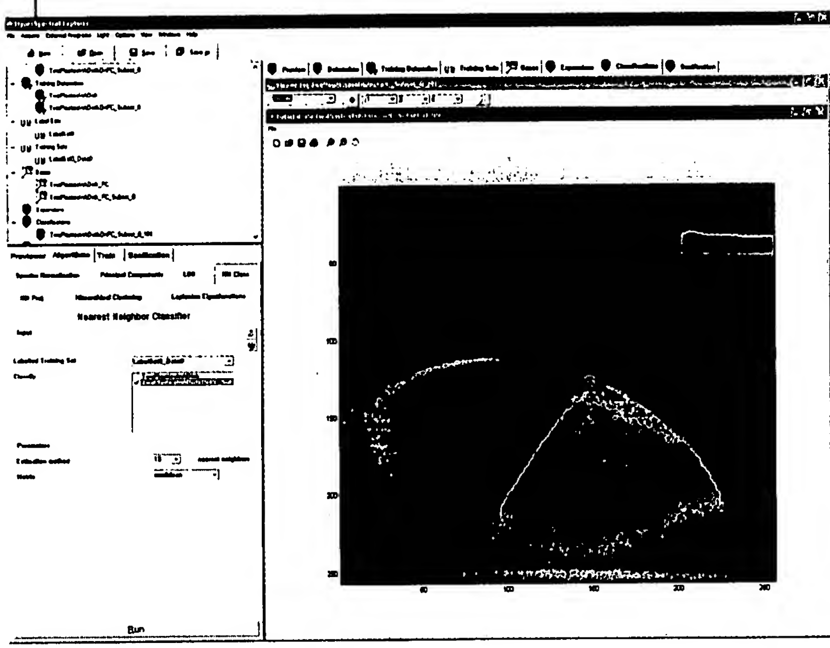
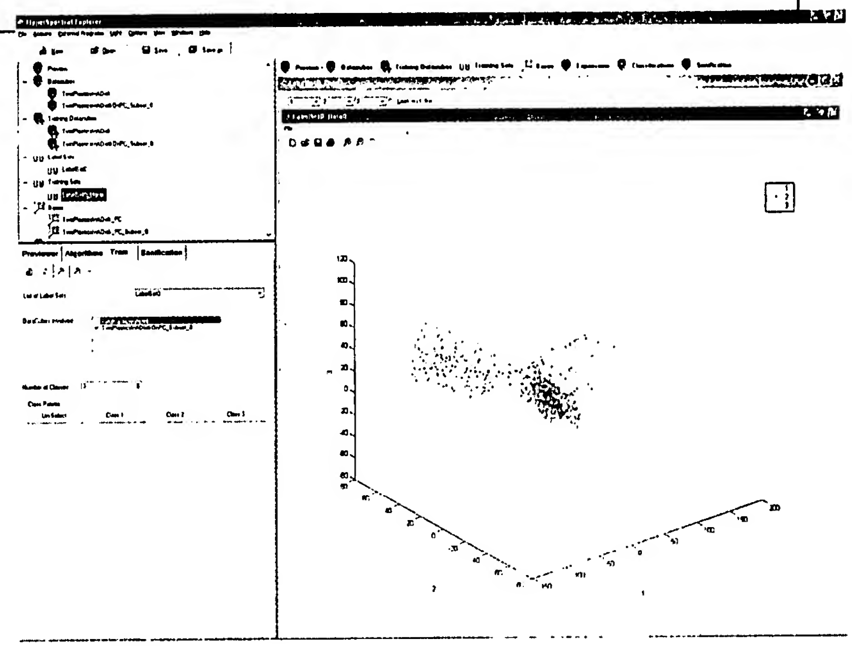


Fig 47: HSE: Different Views

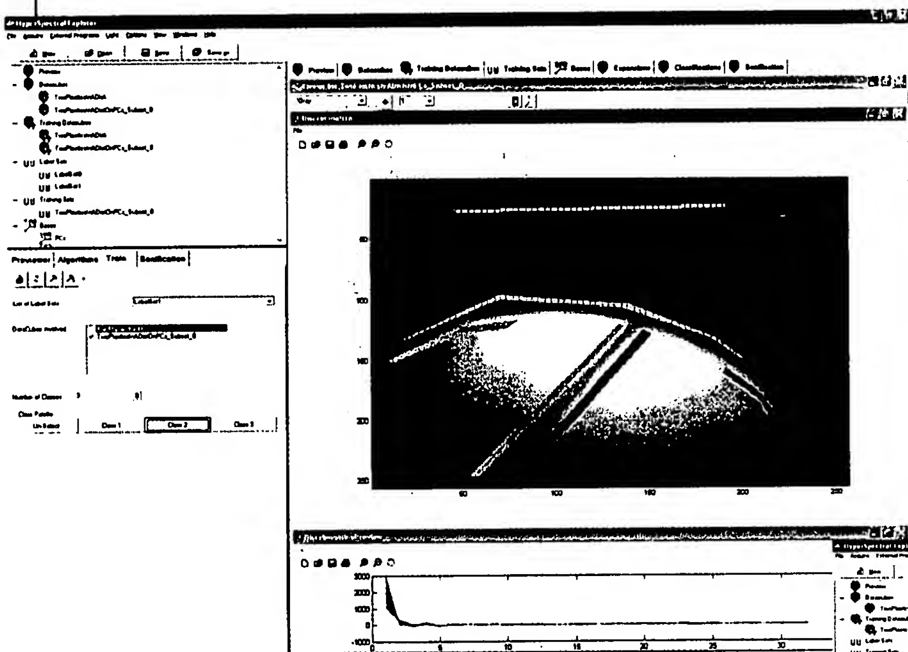


Three Color Component View

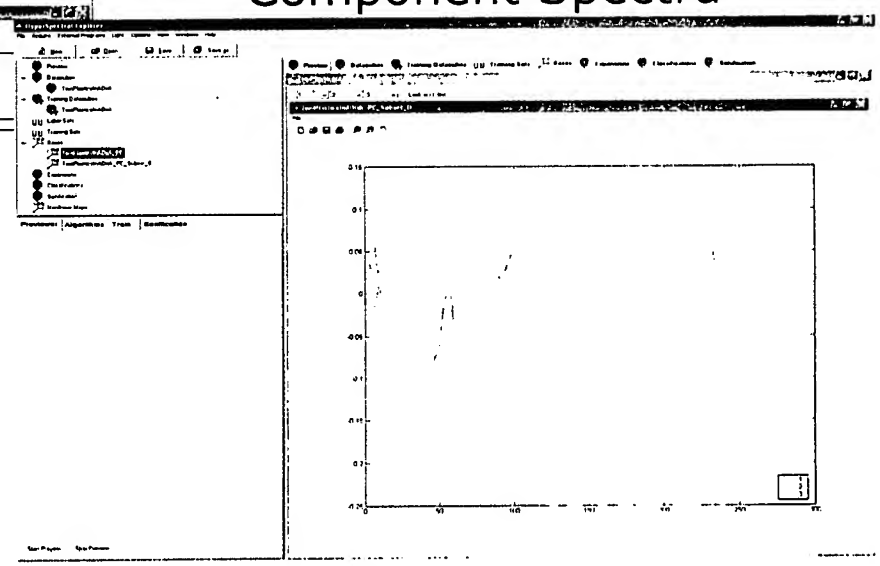


Clustering in Three Space

Fig 48: HSE: Choose Data



Choosing Data for Training Sets



Choosing Individual Component Spectra

Fig 49: NSTIS App Software